EFFECTS OF FEEDING RACTOPAMINE (PAYLEAN®) TO IMMUNOLOGICALLY CASTRATED (IMPROVEST®) PIGS ON GROWTH PERFORMANCE, CARCASS YIELDS, AND FURTHER PROCESSING CHARACTERISTICS

BY

BRADLEY KEVIN LOWE

DISSERTATION

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Doctoral Committee:

Assistant Professor Anna Dilger, Chair
Professor Floyd McKeith, Co-Chair
Associate Professor Cliff Shipley
Professor Hans Stein
Scott Carr, Ph.D., Elanco Animal Health

ABSTRACT

The objective of this dissertation was to evaluate the effects of feeding ractopamine hydrochloride (RAC; Paylean, Elanco Animal Health, Greenfield, IN) on growth performance, carcass characteristics, fresh meat quality, and further processing characteristics of immunologically castrated (IC; Improvest, Zoetis, Kalamazoo, MI) pigs. With costs of production rising in the swine industry, producers are constantly seeking methods to improve growth performance while keeping production costs minimal. Two technologies that have been beneficial in helping producers improve feed efficiency and save on feed costs is the use of RAC and immunological castration. Ractopamine hydrochloride is an orally active β-agonist that repartitions nutrients away from fat deposition and towards lean deposition. Animals become less efficient over the course of production, especially during the finishing phase when the body has decreased the rate at which it is accumulating muscle and increased the rate at which it is accumulating fat. These changes often result in increasing average daily gains (ADG), improving feed conversion (G:F), increasing slaughter weights and carcass weights, improving carcass muscling, and improving carcass cutability. Similarly, immunological castration through the use of Improvest allows producers to take advantage of the increased efficiency of young intact pigs by delaying castration until later in production. Boars are the most efficient of all sexes of swine mainly due to increased testosterone levels and the effects they have on appetite and lean accretion. However, as boars age and reach market weights, the meat from these pigs often has an unpleasant odor referred to as 'boar taint' due to the affects that testosterone has on the body's ability to clear androstenone and skatole from the system. Androstenone is a testicular steroid that has no hormonal activity but functions merely as a sex pheromone. Contrary to androstenone which is only produced in males, skatole is produced by both males

and females via bacterial digestion of the amino acid tryptophan in the hind gut of pigs from where it is absorbed and, if not cleared by the liver, accumulates in fatty tissues. Improvest works through a two dose program that inhibits production of both luteinizing hormone and follicle stimulating hormone which ultimately inhibits testicular activity. This inhibition in testicular activity decreases testosterone production and allows the body to metabolize and clear away androstenone and skatole. Using Improvest in swine operations allows producers to take advantage of the increased efficiency and carcass leanness commonly associated with raising boars without having any boar taint issues with meat from those pigs. While the reports of feeding RAC, as well as immunological castration, are extensive and numerous, there is very limited data evaluating the use of these technologies together. Therefore, the objectives of these studies were to evaluate the effects of feeding RAC (5 mg/kg for up to 33 d) on growth performance, carcass characteristics, fresh meat quality, and further processing characteristics of IC pigs managed in a commercial setting. Feeding RAC during the last 33 d of finishing increased ADG by 17% and increased G:F by 18%. Carcasses from RAC-fed pigs were 2.3 kg heavier, had 2.2 mm deeper loins, and were estimated to be 0.4 percentage units leaner than control-fed carcasses. In terms of carcass cutability, feeding RAC increased boneless lean, bone-in lean, and total carcass cutting yields by 0.70, 0.76, and 0.70 percentage units, respectively. There was very little impact of feeding RAC on fresh meat quality parameters including loin color, marbling, and firmness scores, pH, and tenderness; however, feeding RAC increased loin moisture and decreased loin fat in physically castrated (PC) carcasses while having no effects in IC carcasses. This was also seen when evaluating further processing characteristics where RAC increased leanness of cured hams and bellies from PC carcasses while having no impact on hams and bellies from IC carcasses. Over the entire growth study (120 d), IC pigs gained 2.6% faster,

consumed 4.6% less feed, and were ultimately 7.3% more feed efficient than PC pigs. While carcass weights of PC and IC pigs were similar, IC carcasses had 1.3 mm less fat which is indicative of IC carcasses having greater amounts of lean than PC carcasses. This was made apparent when evaluating carcass cutting yields where IC carcasses had 1.19, 1.63, and 1.32 percentage units advantages over PC carcasses for boneless lean, bone-in lean, and total carcass cutting yields, respectively. While immunological castration had no impact on loin color scores, loins from IC carcasses had less marbling, were softer, and were slightly less tender than those from PC carcasses. The effects of immunological castration on carcass leanness were also seen when evaluating further processing characteristics where cured hams and bellies from IC carcasses had more moisture and less fat than those from PC carcasses. When evaluating the technologies together, RAC-fed IC pigs grew 29% faster and were 17% more feed efficient than control-fed PC pigs during the last 33 d of feeding. Furthermore, RAC-fed IC carcasses were 2% heavier, had 7% less fat, and were estimated to be 0.59 percentage units leaner than control-fed PC carcasses. In terms of carcass cutting yields, RAC- fed IC carcasses had 1.9, 2.4, and 2.0 percentage units greater boneless lean, bone-in lean, and total carcass cutting yields, respectively, than control-fed PC carcasses. The combination of the two technologies had no more impact on fresh meat quality than using either technology alone. The results from these studies support the ideas that these two technologies are additive in terms of effects on growth performance, carcass characteristics, and carcass cutting yields while having minimal impact on fresh meat quality.

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Chapter 1

REVIEW OF LITERATURE

INTRODUCTION

Recent inclusion of metabolic modifiers such as β-adrenergic agonists in finishing diets has aided pork producers in improving growth performance of finishing pigs and producing pigs with leaner carcasses. Ractopamine-HCl (Paylean®; Elanco Animal Health, Greenfield, IN) improves growth efficiency and produces leaner carcasses by redirecting nutrients to increase the amount of lean meat in high value cuts (Apple et al., 2007b). Additionally, immunization against gonadotropin-releasing factor (GnRF; Improvest®; Pfizer Animal Health, Kalamazoo, MI) takes advantage of the ability of an intact male pig to deposit muscle more efficiently than surgically-castrated pigs and reduce the incidence of boar taint from intact male pigs (Campbell et al., 1989; Dunshea et al., 2001; Boler et al., 2011a). While these two technologies have been evaluated separately, there is limited research evaluating the combination of ractopamine-HCl inclusion and immunocastration on growth performance, carcass characteristics and yields, meat quality, and further processing characteristics.

RACTOPAMINE HYDROCHLORIDE

Mode of Action of β-agonists Including Effects on Protein and Lipid Metabolism

Synthetically-produced β-agonists are similar in structure, biosynthetic sequence, and function to endogenous catecholamines (i.e., epinephrine, norepinephrine, and dopamine) produced by mammals (NRC, 1994). These compounds circulate in the blood, act at sites removed from their origin, and regulate a wide range of physiological responses in many tissues. Most catecholamines have the following similar structures: an aromatic ring with three binding sites at the end of the carbon chain, a hydroxyl group on the β-carbon, an aliphatic group adjacent to the α-carbon, and an R group adjacent to the aliphatic nitrogen. For ractopamine-HCl

(RAC), the aromatic ring has –OH bound at the para- position and the R-group is an alkylphenol group. The physiological activity of β-agonists is dependent on its innate activity at the receptor and on its absorption, rates of metabolism and elimination, and distribution to target tissues.

Responses to these compounds are also related to receptor subtype and abundance. The majority of mammalian cells do not have a pure population of any specific β-receptor subtype. While ractopamine has the ability to bind to several β-receptors it has a higher affinity and is preferential to β-1 subtype receptors (Anderson et al., 1991). Of all the β-receptors present in pig tissues, β-1 receptors account for approximately 60% of the receptors in skeletal and 70-80% in adipose tissue (Mills and Mersmann, 1995). Skeletal muscle and adipose tissue have β-adrenergic receptors as evidenced by the stimulation of glycogenolysis and lipolysis, respectively, by epinephrine, norepinephrine, and the analog isoproterenol both in vitro and in vivo (Mills and Mersmann, 1995).

The ability of certain compounds (e.g., caffeine, nicotine, and epinephrine) to directly or indirectly modify metabolism and mobilization of stored energy sources such as glycogen in muscle and lipid in adipose tissue has been reported (Cunningham, 1965) and led to the concept of using epinephrine-like products (i.e. β-agonist) to adjust animal growth and improve efficiency. During protein turnover, growth efficiency is decreased due to energy lost during breakdown and resynthesis of proteins (Pringle et al., 1993). The hypertrophic response of skeletal muscle after chronic, high dose β-agonist administration has been associated with a decrease in protein degradation, an increase in protein synthesis, or a combination of both mechanisms (Lynch et al., 2008). B-agonists, acting through a G-protein coupled receptor, inhibit energy storage and protein degradation while stimulating energy mobilization and protein synthesis. It is believed that β-agonists act primarily inhibit protein degradation via the Ca^{2+}

dependent pathway (Lynch et al., 2008). Stimulation of β-receptor signaling increases expression of m-calpain and calpastatin which has been attributed to protein kinase-A (PKA)-dependent phosphorylation of proteins including calpastatin (Hawkins et al., 1995). In terms of β-agonist mediated protein synthesis, β-agonist/adenylate cyclase/cyclic AMP (cAMP)/PKA signaling initiates transcription of a number of proteins and thus promotes protein synthesis (Pearen et al., 2006) either via direct PKA-mediated phosphorylation of cAMP response binding protein (CREB), or via a modulator that acts on second-generation target genes (Lynch et al., 2008). Animals treated with RAC displayed stimulated myofibrillar protein synthesis increased mRNA of several skeletal muscle proteins (Adeola et al., 1992; Mersmann, 1998) leading to the understanding that RAC acts by increasing protein synthesis.

Ligands for β-receptors were first identified for their anti-obesity properties; adipose tissue accretion decreases with β-agonist binding and the associated cellular responses. Beta-agonists regulate lipid turnover via both fatty acid synthesis and fatty acid β-oxidation (Ricks et al., 1984). Using glucose-derived acetyl-CoA from glycolysis, the tricarboxylic acid (TCA) cycle converts acetyl-CoA to citrate. Citrate is then converted back to acetyl-CoA, by the enzyme ATP citrate lysase, which is now available in the cytoplasm for fatty acid biosynthesis. This acetyl-CoA is then converted to malonyl-CoA through the addition of CO_2 and breakdown of adenosine triphosphate (ATP). Acetyl-CoA carboxylase (ACC), a biotin dependent enzyme, drives the formation of malonyl-CoA which is used as the basic fatty acid chain forming unit.

Because fatty acids stored in adipose tissue represent more than 80% of the body's stored energy, they are easily mobilized and utilized for energy. The basic form of this stored energy is triacyl glyceride (TAG), which is composed of a glycerol molecule with three fatty acids attached. During fatty acid β-oxidation, TAGs found in adipose tissue are broken down to

release glycerol and fatty acids, via TAG lipase. This TAG lipase is cAMP-dependent and activated by glucagon and epinephrine. Glycerol from TAG enters into glycolysis and produces ATP. The free fatty acid enters the outer membrane of the cell and is converted to acyl-CoA, derivative of energy, via acyl-CoA synthetase.

Direct activation of β-receptors in adipose tissue promotes stimulation of lipolysis associated with reduction in lipogenesis and of insulin action (Lafontan et al., 1988; Philipson, 2002). B-agonists stimulate lipolysis through PKA-mediated phosphorylation of hormone sensitive lipase (HSL; Koopman et al., 2009). Phosphorylation of HSL results in an increase in triacylglycerol, diacylglycerol, and monoacylglycerol hydrolysis and release of free fatty acids from adipocytes (Holm, 2003). Phosphorylation of PKA inactivates glucose transport and acetyl-CoA carboxylase and increases expression of genes associated with oxidation of fatty acids including PPARγ and pyruvate dehydrogenase kinase (Mills and Mersmann, 1995; Mersmann, 1998; Koopman et al., 2009).

Therefore, the overall effect of RAC feeding is increased protein accretion resulting from inhibited protein degradation and stimulated protein synthesis. Additionally, RAC feeding stimulates lipolysis by inhibiting lipogenesis and phosphorylation of HSL. These events lead to production of animals with increased muscle mass and decreased fat content when fed RAC.

Changes in Nutritional Requirements When Feeding Ractopamine

With feeding RAC, diets need to be sufficient to support increased protein accretion. Commercial swine operations typically feed diets with approximately 3.4 Mcal of ME/kg, coupled with decreases in essential amino acids to optimize profitability during the final stages of the finishing period (Apple et al., 2004); however, these finishing diets are supplemented with synthetic amino acids to meet the ideal amino acid ratios of (Chung and Baker, 1992). These

decreased amino acid concentrations may not be sufficient to meet the requirements of pigs fed RAC (Schinkel et al, 2000, 2003; Webster et al., 2002). Additionally, the ratio of lysine:energy (Lys:ME) in RAC supplemented pigs may have a greater effect on performance and carcass composition than absolute energy intake. Energy density itself does not have an appreciable effect on modifying the efficiency of pigs fed RAC (Williams et al., 1994; Dunshea et al., 1998; Apple et al., 2004); however, efficiency, including body weight gain, gain:feed, and lean deposition improves as Lys:ME increases in pigs fed RAC (Schinkel et al. 2000; Webster et al., 2002; Apple et al., 2004). Therefore, when pigs are fed RAC, the diets need to contain a minimum of 16% crude protein or its equivalent obtained by supplemental amino acid to reach 0.85-0.95% standardized ileal digestible lysine.

Effects on Growth and Composition

Although dosages of RAC vary, for this review whenever possible, only comparisons between feeding 0 and 5 mg/kg RAC will be the focus. Supplementation with RAC resulted in increases in average daily gain (ADG) of finishing pigs ranging from 0.05 to 0.21 kg/d (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004, 2005; See et al., 2005; Patience et al., 2009). However, the effects on average daily feed intake (ADFI) are not as consistently detected as those of RAC supplementation on ADG. Most report no difference or a decrease in ADFI for pigs fed 5 mg/kg RAC when compared to control-fed pigs (Watkins et al., 1990, Stites et al., 1991, Herr et al., 2001) where others have reported feeding 5 mg/kg increased ADFI when compared to control-fed pigs (Armstrong et al., 2004; Armstrong et al., 2005). Supplementation with RAC also improves gain:feed (G:F). Pigs supplemented with 5 mg/kg RAC experienced increases in G:F ranging from 0.02 to 0.05 kg/kg (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004, 2005; Patience et al., 2009). After a meta-

analysis of available data, feeding RAC at 5 mg/kg increased ADG by 12.5%, lowered ADFI by 0.3%, and improved G:F by 6.7% (Apple et al., 2007b).

In addition to production gains, RAC supplementation increases the value of carcasses. Carcass weights of pigs fed 5 mg/kg RAC have ranged from 0.4 to 6.0 kg heavier than those of control-fed pigs (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004; See et al., 2005; Carr et al., 2009; Kutzler et al., 2011). Changes in dressing yield with RAC supplementation have been reported ranging from 0.2 to 1.5% greater than those of control-fed pigs (Watkins et al., 1990; Stites et al., 1991; Armstrong et al., 2004; See et al., 2005). Changes in total carcass composition are evidenced by changes in fat depth over the loin eye, changes in loin muscle (LM) depth and area, and carcass lean yields. Reductions in carcass fatness of pigs fed 5 mg/kg RAC range from 0.09 to 0.18 cm (Watkins et al., 1990; Uttaro et al., 1993; Patience et al., 2009) but others have reported no differences in carcass fatness (Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004; See et al., 2005). However, Apple, Rincker et al. (2007) reported that after a meta-analysis of available data, pigs fed 5 mg/kg RAC had 0.04 cm less fat over the loin eye. With regards to lean gain, pigs fed 5 mg/kg RAC had 2.6 to 5.0 cm^2 larger LM areas when compared to control-fed pigs (Watkins et al., 1990; Stites et al., 1991; Armstrong et al., 2004). Increases in LM depth ranging from 0.26 to 0.50 cm for pigs fed 5 mg/kg RAC when compared to control-fed pigs have also been reported (See et al., 2005; Patience et al., 2009). Additionally, Carr et al. (2009) reported carcasses from heavy-weight pigs fed 5 mg/kg of RAC had higher muscling scores when compared to control-fed pigs (2.74 vs. 2.54). After a meta-analysis of available data, Apple et al. (2007) reported that estimated or calculated fat-free lean yield was increased by 0.9% for pigs fed 5 mg/kg of RAC when compared to control-fed pigs. This is in agreement with Patience et al. (2009) who reported an

approximately 0.97% increase in carcass leanness of carcasses from pigs fed 5 mg/kg RAC. However, prediction equations using standard carcass measurements may actually underestimate the effect of RAC on carcass lean content (Mowrey et al., 1991; Gu et al., 1992). Using carcass dissection, lean muscle composition increased between 2.0 and 5.1% for pigs fed 5 mg/kg RAC when compared to control-fed pigs (Watkins et al., 1990, Stites et al., 1991, Herr et al., 2001). In summary, pigs fed 5 mg/kg RAC have improved ADG while consuming the same amount of feed as control-fed pigs resulting in increased G:F. Pigs fed RAC also possess increased muscling and increased carcass leanness with similar or reduced amounts of carcass fat.

Effects on Pork Quality Including Meat Tenderness and Processing Characteristics

Feeding RAC, especially at low levels (< 7.4 mg/kg), during the final stages of finishing has little to no detrimental effects on pork quality. Muscle pH affects multiple meat quality aspects including color, firmness, and water holding capacity; therefore, pH is routinely measured to evaluate overall pork quality. Feeding RAC at 5 mg/kg did not alter LM pH (Stites et al., 1994; Herr et al., 2001; Rincker et al., 2005; Patience et al., 2009; Leick et al., 2010). Additionally, feeding RAC at 5 mg/kg did not affect LM firmness scores (Stites et al., 1994; Rincker 2005; Carr et al., 2009; Leick et al., 2010). Feeding RAC did not alter drip loss of LM from treated pigs (Rincker et al., 2005; Patience et al., 2009).

Fresh pork color is one of the most important quality characteristics affecting consumer perception of freshness at the point of purchase (Brewer and McKeith, 1999). Feeding pigs 5 mg/kg RAC had no detrimental effects on fresh pork color (Watkins et al., 1990; Stites et al., 1994; Herr et al., 2001; Rincker et al., 2005; Carr et al., 2009; Patience et al., 2009). Most packers measure and sort pork based on instrumental color measurements, especially lightness (L^*; greater value indicates a lighter color), redness (a^*; greater value indicates a redder color), and yellowness (b^*; greater value indicates a more yellow color) values. Feeding pigs 5 mg/kg

RAC did not alter *L** values of LM when compared to LM from control-fed pigs (Herr et al., 2001; Armstrong et al., 2004; Rincker et al., 2005; Patience et al., 2009). However, *a** values for LM of control-fed pigs were higher (i.e., redder) than those of pigs fed 5 mg/kg RAC (Rincker et al., 2005; Patience et al., 2009). The effects of feeding RAC on *b** values is inconsistent where some have reported no differences in LM *b** between pigs fed 5 mg/kg RAC and control-fed pigs (Herr et al., 2001; Armstrong et al., 2004; Rincker et al., 2005) while others have reported that LM of control-fed pigs had higher (i.e., more yellow) *b** values when compared to LM from pigs fed 5 mg/kg RAC (Patience et al., 2009).

Marbling or intramuscular fat is often associated with palatability of pork. Multiple reports indicate that there are no differences in marbling scores of LM from control-fed when compared to those fed 5 mg/kg RAC (Stites et al., 1991; Armstrong et al., 2004; Rincker et al., 2005; Carr et al., 2009; Patience et al., 2009); however, Watkins et al. (1990) interestingly reported that pigs fed 5 mg/kg RAC had LM with more marbling when compared to LM from control-fed pigs. After a meta-analysis of available literature, Apple et al. (2007) reported that feeding RAC does not impact marbling scores. Additionally, feeding 5 mg/kg of RAC has no effect on extractable lipid content of LM when compared to LM from control-fed pigs (Rincker et al., 2005; Apple et al., 2007b).

The effect of RAC on tenderness remains controversial because there is no clear trend from available literature. Stites et al. (1994) and Rincker et al. (2005) both report feeding pigs 5 mg/kg RAC did not affect LM Warner-Bratzler shear force (WBSF) values. Similarly, there were no differences in sensory evaluations of tenderness comparing LM from control-fed pigs (Stites et al., 1994; Rincker et al., 2005). However, Patience et al. (2009) reported that feeding pigs 5 mg/kg RAC lead to a 12 and 21% increase (i.e., less tender) in LM WBSF values for non-

enhanced and enhanced loins, respectively, when compared to those from control-fed pigs. Additionally, Patience et al. (2009) reported that LM from pigs fed 5 mg/kg RAC were less tender than LM from control-fed pigs for both non-enhanced and enhanced pork loins when evaluated by a trained sensory panel.

Some pork processors are concerned that RAC feeding alters belly quality. Feeding RAC decreases the quantity of saturated fatty acids (Engeseth et al., 1992; Perkins et al., 1992; Apple et al., 2007a) and increases polyunsaturation of pork fat (Carr et al., 2005; Xi et al, 2005; Weber et al., 2006). However, RAC feeding did not alter belly length, width, thickness, and trimmed weight (Stites et al., 1991; Leick et al., 2010), or belly firmness (Carr et al., 2005; Scramlin et al., 2008; Leick et al., 2010). Pump uptake and cook loss did not differ between RAC and control fed pigs (Stites et al., 1991; Leick et al., 2010). However, bellies from pigs fed 7.4 mg/kg RAC had lower cooked yields than those from pigs fed 0 and 5 mg/kg RAC with no difference in yields of pigs fed 0 and 5 mg/kg RAC (Scramlin et al., 2008). Additionally, bacon produced from pigs fed 5 mg/kg RAC had greater total slice area, total slice length, secondary lean length, and total lean area when compared to those from pigs fed 0 mg/kg RAC; however, there were no differences when evaluating secondary lean length and proximate composition of bacon slices (Scramlin et al., 2008).

In regards to ham quality, feeding pigs 7.4 mg/kg RAC had no effect on ultimate pH, L^*, and a^* values of the semimembranosus (Fernández-Dueñas et al., 2008; Boler et al., 2011b). However, the findings of the effects of RAC feeding on semimembranosus b^* are inconsistent similar to those in LM. Feeding RAC either has no effect on (Boler et al., 2011b) or increases (Fernández-Dueñas et al., 2008) b^* values when compared to control fed pigs. Pigs fed RAC produce hams with increased green weights, pumped weights, cooked weights, and cooked yield

(Stites et al., 1991; Uttaro et al., 1993; Boler et al., 2011b). In summary, feeding RAC has no negative effects on meat quality including fresh meat characteristics, tenderness, and further processed product quality of carcasses or muscles from treated pigs.

IMMUNOLOGICAL CASTRATION

Pigs grow most efficiently as entire males (boars); however, meat from mature boars has a characteristically unpleasant odor referred to as boar taint. Boar taint compromises the eating experience of fresh meat from entire male pigs. Boar taint has been traditionally controlled by physical castration of male pigs at 7-10 d of age. Disadvantages of physical castration include decreased growth rate and possibilities of infection and even death. In contrast, immunological castration can be performed much later in life than physical castration and therefore can take advantage of the growth characteristics associated with boars. Outside sources are beginning to put extra emphasis on pig producers to become more economically efficient, while also reducing environmental impact and improving animal welfare (Hennessy, 2008). Immunocastration gives producers an instrument to control boar taint while benefiting from the natural growth and carcass characteristic advantages of boars. Recently approved for use in the United States, Improvest® (Pfizer Animal Health, Kalamazoo, MI) is an immunological product for swine that stimulates the pig's immune system to produce antibodies against gonadotropin releasing factor (GnRF), temporarily blocking its activity.

Boar Taint

Boar taint, an objectionable odor and flavor that is sometimes detected when pork is cooked, is caused by the production of two compounds, androstenone and skatole (Babol et al., 1996). Threshold concentrations greater than 1.0 µg/g in subcutaneous fat for androstenone and 0.20 µg/g for skatole cause negative consumer reactions (Bonneau et al., 2000). Androstenone is a testicular steroid that has no hormonal activity but functions as a sex pheromone (Claus et al.,

1994). Being highly lipophilic, androstenone accumulates in fat where it can contribute to boar taint (Hennessy, 2008). Contrary to androstenone which is only produced in males, skatole is produced by males and females (DeMoss and Moser, 1969). Skatole is produced via bacterial digestion of the amino acid tryptophan in the hind gut of the pig from where it is absorbed and, if not cleared by the liver, accumulates in fatty tissues (Hennessy, 2008). In intact male pigs, the liver is less efficient at metabolizing skatole than in females and castrated males, leading to an accumulation of skatole (EFSA, 2004). Additionally, while sensitivity to androstenone is variable and approximately 25% of consumers are unable to smell the substance, skatole is uniformly detected by all persons due to its unpleasant fecal odor (Claus et al., 1994).

Improvest® Mode of Action

The following is adapted from Pfizer Animal Health's Technical Bulletin: Improvac® Mode of Action. Improvac/Improvest® (Pfizer Animal Health, Kalamazoo, MI) is an immunological product for the control of boar taint in intact male pigs. The antigen present in Improvest® is comprised of a synthetic, incomplete analog of natural gonadotropin releasing factor (GnRF) which is covalently linked to a carrier protein. The GnRF analog alone is not immunologically active. Once conjugated to a larger carrier protein, the analog prevents any binding to the pituitary GnRF receptor and thus eliminates potential for GnRF hormonal activity.

Injection with Improvest® stimulates the immune system to produce specific antibodies that neutralize GnRF, thus blocking gonadal function and the accumulation of boar taint compounds. Gonadotropin releasing factor is the key hypothalamic regulator of testicular function. Secreted from the hypothalamus, GnRF binds to receptors specific for GnRF on the pituitary gland where it stimulates production of luteinizing hormone (LH) and follicle stimulating hormone (FSH). Both LH and FSH stimulate and control the growth and activity of the testes leading to sexual maturity, behavioral changes, and boar taint in male pigs. Full

immunization with Improvest® consists of an initial priming dose followed by a second dose at least 4 weeks after the initial dose. The initial dose primes the pig's immune memory cells but does not stimulate effective levels of anti-GnRF antibodies. From this point until the second dose, the pig continues to both grow and behave as a functioning boar. The second dose, administered close to slaughter (between 3 and 10 weeks prior to slaughter), produces high levels of specific anti-GnRF antibodies. These bind to and neutralize endogenous GnRF. This process temporarily stops stimulation of the pituitary gland inhibiting testicular function. Furthermore, accumulation of boar taint compounds is suppressed and compounds already present are able to be cleared. This mainly results from decreased production of testosterone which in turn decreases androstenone production (Dunshea et al., 2001). Reduced testosterone also allows the liver to become more efficient at metabolizing and clearing accumulated skatole resulting in reduced levels comparable to those found in female and physically castrated pigs. Approximately 3 to 4 weeks after the second dose, the levels of androstenone and skatole are below the boar taint thresholds of 1.0 and 0.2 µg/g, respectively (Bonneau et al., 2000; Dunshea et al., 2001).

Effects on Growth and Composition

Through the use of immunocastration, castration can be delayed until shortly before slaughter. Because boars are more efficient and produce leaner carcasses than physical castrates (Xue et al., 1997), a system of immunocastration results in improved efficiency and higher value carcasses. In several studies comparing physical castrates, immunocastrated (IC) barrows, and boars, IC barrows had higher ADG and improved feed conversion when compared to physical castrates over the entire production phase (Dunshea et al., 2001; Turkstra et al., 2002). Even after second injection (castration), ADG was increased 10% compared to boars and increased 7% compared with physical castrates in pigs harvested at 23 weeks of age (Dunshea et al., 2001).

Furthermore, ADG of IC barrows was improved 30% compared to boars and improved 32% compared physical castrates during the last 4 weeks of feeding prior to harvest in pigs harvested at 26 weeks of age. With the exception of one study that reported no differences in growth performance (Jaros et al, 2005), IC barrows have had greater ADG (Pauly et al., 2009; Morales et al., 2011), increased ADFI (Fabreaga et al., 2010), and improved feed conversion (Pauly et al., 2009; Morales et al., 2011) when compared to physical castrates. During the time post-second injection, there is a positive relationship between time post second injection and ADFI for immunocastrates (Lealiifano et al., 2011).

In terms of carcass characteristics, immunocastrates consistently have lower dressing yields when compared to physical castrates (Bonneau et al., 1994; Dunshea et al., 2001; Pauley et al., 2009; Boler et al., 2012; Morales et al., 2011). Differences in dressing yield can be attributed to the presence and removal of testicles and scrotal skin (Boler et al., 2012) along with heavier organ weights for immunocastrates (Pauly et al., 2009). Despite having lower dressing yields, immunocastrates have consistently produced leaner carcasses when compared to barrows due to having less fat and increased muscling (Dunshea et al., 2001; Jaros et al., 2005; Pauly et al., 2009; Morales et al., 2011). This is to be expected as immunocastrates have growth characteristics similar to those of boars prior to the second injection with Improvest®. In terms of lean meat yields, carcasses from immunocastrates have greater yields for components of the shoulder, loin, and ham when compared to carcasses from physical castrates (Pauly et al., 2009; Boler et al., 2012). When compared to physical castrates, carcass cutting yields were increased 2.5% in IC barrows (Boler et al., 2011c; Boler et al., 2012). Cutting yields of carcasses from immunocastrates also increased as lysine level in the diet was increased (Boler et al., 2011c). In

summary, immunocastration takes advantage of the growth performance of boars and produces leaner carcasses when compared to physically castrated pigs.

Effects on Fresh Meat Quality and Processing Characteristics

Like any new technology, there are concerns with immunocastration regarding the effect it may have on pork quality and acceptability. Use of Improvest® does not affect LM pH (Pauly et al., 2009; Boler et al., 2012; Morales et al., 2011), objective color attributes, subjective color, and drip loss (Boler et al., 2012). The results of immunocastration on LM lipid content are inconsistent where some have reported no differences in extractable lipid content and marbling of LM from immunocastrates when compared to physical castrates (Boler et al., 2011c; Morales et al., 2011; Batorek et al., 2012); whereas Boler et al. (2012) reported marbling scores and extractable lipid content was lower for LM from immunocastrates when compared to physical castrates. Boler et al. (2012) also reported that as time post-second injection increased, a* values increased (i.e. became redder), b* values increased (i.e. became more yellow); marbling scores decreased, moisture content decreased, extractable lipid increased, and drip loss increased. Shear force at 14 d postmortem is not different when comparing LM from immunocastrates and physical castrates (Batorek et al., 2012; Boler et al., 2012).

In terms of belly quality, bellies from IC barrows are narrower, softer, and thinner than bellies from physical castrates while there are no differences in length (Boler et al., 2011a; Boler et al., 2012). However, bellies become firmer as time post-second injection is increased (Boler et al. 2012). Softer bellies could be the result of IC barrows having lower monounsaturated fatty acid (MUFA) concentrations, greater polyunsaturated fatty acid (PUFA) concentrations, and overall higher iodine value (IV) when compared to physical castrates (Boler et al., 2012). However, in another study, Boler et al. (2011a) reported no differences in MUFA, PUFA, and IV between immunocastrates and physical castrates that had been fed the same diet.

There were no differences between immunocastrates and physical castrates when evaluating belly processing characteristics including green weight, pump weight, equilibrium weight, cooked weight, and cooked yield (Boler et al., 2012). However, bellies from immunocastrates had greater pump uptake and less cook yield when compared to those from physical castrates (Boler et al., 2012). As time post-second injection increased, pump weight, equilibrium weight, cooked weight, and cooked yield of IC barrows increased (Boler et al., 2012). When fed the same diet, bellies from immunocastrates did not differ from those of physical castrates for any belly processing characteristics (Boler et al., 2011a).

Bacon from immunocastrates had greater moisture (Boler et al., 2011a, Boler et al., 2012) and less fat content (Boler et al., 2012) when compared to physical castrates. When fed the same diet, there were no differences in bacon slice length, total slice area, secondary lean length, secondary lean area, and total slice lean area when comparing immunocastrates and physical castrates (Boler et al., 2011a). However, bacon slices from immunocastrates are narrower in terms of slice width when compared to bacon from physical castrates fed the same diet (Boler et al., 2011a). No differences were detected between immunocastrates and physical castrates fed the same diet for ham processing characteristics including green weight, pump weight, pump uptake, equilibrium weight, stuffed weight, cooked weight, cook loss, cooked yield, moisture content, fat content, protein fat-free, cured color, and break strength (Boler et al., 2011a). Overall, Improvest® treatment does not have any negative effects on meat quality including tenderness and further processing characteristics.

COMBINATORY EFFECTS OF RACTOPAMINE AND IMPROVEST®

There is limited data available to evaluate the effects of feeding RAC to immunocastrated pigs. Unfortunately, there is no published data that compares feeding RAC to physical castrates

and immunocastrates simultaneously. Reviewing the available literature however, it appears that the two technologies are additive, if not synergistic, for growth performance in the sense that growth is improved regardless of sex. Both technologies use unique mechanisms to improve growth and increase lean deposition. Knowing this, the performance of the technologies together should be additive and supersede the effects of either one alone.

In a study evaluating sex and the use of a RAC step-up program where intact boars, gilts, and immunocastrates were fed either a control diet (0 mg/kg RAC) for 31 d or 5 mg/kg RAC for 14 d followed by 10 mg/kg RAC for 17 d, there were no interactive effects of sex and RAC on body weight (BW), ADG, and G:F (Rikard-Bell et al., 2009). There was an interaction of sex and RAC in evaluating ADFI such that the immunocastrates fed RAC had the greatest reduction (6.0%) in ADFI of the three sexes (Rikard-Bell et al., 2009). Feeding RAC increased body weight by 2.0%, increased ADG by 5.4%, and improved G:F by 8.8% when averaged across all sexes evaluated (Rikard-Bell et al., 2009). Immunocastrates were the heaviest, had the greatest ADFI, and were the fastest growing of the sexes (Rikard-Bell et al., 2009). In terms of efficiency, G:F for immunocastrates was greater than that for gilts but less than that of boars (Rikard-Bell et al., 2009). In immunocastrates, feeding RAC increased body weight by 1.4%, decreased ADFI by 6.0%, increased ADG by 2.4%, and improved efficiency by 9.1% (Rikard-Bell et al., 2009). In a similar study evaluating sex and feeding RAC, intact boars and immunocastrates were fed either a control diet (0 mg/kg RAC) for 26 d, 5 mg/kg RAC for 26 d, or a step-up RAC diet where 5 mg/kg RAC was fed for 14 d followed by 10 mg/kg RAC for 12 d (5/10). Feeding RAC increased final BW by 2.2%, increased ADG by 8.7%, decreased ADFI by 1.6%, and improved feed conversion by 8.2% when averaged across both sexes (Moore et al., 2009). Sex effects included greater final BW by 2.2%, increased ADG by 8.0%, and increased

ADFI by 10.3% for immunocastrates when compared to boars (Moore et al., 2009). For immunocastrates fed RAC, final BW was 1.6% heavier, ADG was 7.1% greater, ADFI was 5.3% less, and feed conversion was improved by 11.3% when compared to immunocastrates not fed RAC (Moore et al., 2009).

Similar to growth performance, feeding RAC improves carcass characteristics of immunocastrates including carcass weight, lean percentage, and fat percentage (Rikard-Bell et al., 2009). Carcasses from immunocastrates fed RAC were 1.9 kg heavier, had 5.8% more lean, and 8.1% less fat than carcasses from immunocastrates fed 0 mg/kg RAC (Rikard-Bell et al., 2009). Additionally, Moore et al. (2009) reported carcasses from immunocastrates fed RAC were approximately 2.5 kg heavier and had 1.4 kg more lean tissue than those from immunocastrates fed 0 mg/kg RAC. Using dual energy x-ray absorptiometry, Rikard-Bell et al. (2009) reported that feeding RAC improved composition of the shoulder, loin, belly, and ham of immunocastrates. Feeding RAC to immunocastrates did not affect pork quality in terms of loin muscle pH, objective color, surface exudate, cooking loss, or Warner-Bratzler shear force (Moore et al., 2009). In conclusion, feeding RAC to immunocastrates improves growth performance and carcass yields without having any detrimental effects on pork quality including pH, color, and tenderness.

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Chapter 2

EFFECTS OF FEEDING RACTOPAMINE TO PHYSICAL CASTRATES, IMMUNOLOGICAL CASTRATES, AND GILTS ON CARCASS CHARACTERISTICS, CUTTING YIELDS, AND FRESH MEAT QUALITY

ABSTRACT

Ninety carcasses were used in this study to evaluate the effects of feeding ractopamine (RAC) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs. Male pigs were randomly assigned to castration method at birth. Pigs in the PC group were physically castrated within 7 d of age and pigs in the IC group were administered Improvest at 16 and 20 wk of age. Finishing diets (0 mg/kg RAC [control], 5 mg/kg, and 7.5 mg/kg RAC) were initiated 7 d following the second Improvest and were fed for the last 24 d of production prior to slaughter. Data were analyzed using PROC MIXED in SAS with the fixed effects of sex, diet, and their interaction; carcass served as the experimental unit for all analyses. Carcasses from PC and IC pigs were similar (P=0.30) in weight but IC carcasses had less (P<0.01) fat than PC carcasses. Gilt carcasses were lighter (P≤0.03) and had less (P<0.01) fat than both PC and IC carcasses. Additionally, RAC-fed carcasses were heavier (P=0.03) than control-fed carcasses. Loins from PC carcasses were darker (P<0.05) than IC loins with gilt loins being similar (P≥0.19) being similar in color to those from the other sexes. Loins from PC carcasses had more (P<0.01) marbling than those from IC carcasses whereas gilt loins were not different (P≥0.42) from the other sexes in terms of marbling. Sex did not affect (P≥0.40) LM area, pH, or firmness scores. Feeding RAC did not affect (P≥0.15) carcass fat, LM area, pH, color, marbling, or firmness scores. Gilt and IC carcasses had greater (P≤0.04) boneless lean yields than PC carcasses

whereas RAC-fed carcasses had greater (P=0.03) total carcass cutting yields than control-fed carcasses. Bellies from PC carcasses were thicker ($P \leq 0.02$) and firmer ($P < 0.01$) than those from gilt and IC carcasses. Bellies from gilt carcasses had greater ($P \leq 0.03$) iodine values than those from PC and IC carcasses; however, there were no differences (P=0.42) between iodine values of PC and IC bellies. Feeding RAC did not affect ($P \geq 0.22$) any fresh belly characteristics evaluated. Overall, immunological castration and feeding RAC appear to be additive in terms of improving carcass characteristics while having minimal impact on fresh pork quality.
Key words: immunological castration, ractopamine, carcass, pork quality

INTRODUCTION

Ractopamine hydrochloride (RAC), commercially available as Paylean® (Elanco Animal Health, Greenfield, IN), is a β-adrenergic agonist for use in finishing swine diets. Studies have shown that feeding RAC increases ADG and improves feed efficiency of finishing pigs (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004, 2005; Apple et al., 2007; Patience et al., 2009) while improving carcass weights and muscling (Carr et al., 2009; Kutzler et al., 2011). Carcasses from RAC-fed pigs also have increased carcass cutting yields when compared to those from control-fed pigs. Furthermore, feeding RAC has been shown to have little impact on fresh meat quality including color, marbling, and firmness scores (Apple et al., 2007) as well as fresh belly characteristics including thickness (Stites et al., 1991) and firmness (Carr et al., 2009).

Improvest (Zoetis, Kalamazoo, MI) is an immunological product that was developed for the control of boar taint in intact male pigs. Immunologically castrated (IC) pigs consistently have greater ADG and improved feed efficiency (Pauly et al., 2009; Morales et al., 2011) when compared to physically castrated (PC) pigs following second Improvest dose. Despite having

decreased dressing percentages (Morales et al., 2011; Boler et al., 2012), IC carcasses are leaner and have greater carcass cutting yields than PC carcasses due to having less fat and increased muscling in the shoulder and ham (Dunshea et al., 2001; Jaros et al., 2005; Pauly et al., 2009; Morales et al., 2011; Boler et al., 2012).

Data documenting the effects of feeding RAC to PC pigs, IC pigs, and gilts simultaneously are limited. Some studies have documented that feeding RAC and immunological castration are additive in terms of increasing ADG and improving feed efficiency (Rikard-Bell et al., 2009 while improving carcass characteristics (Moore et al., 2009); however, these studies reported estimated leanness based on x-ray imaging and not actual carcass cutting yields. Therefore, the objective of this study was to evaluate the effects of feeding three different levels of RAC to PC pigs, IC pigs and gilts on carcass characteristics, cutting yields, and fresh meat quality.

MATERIALS AND METHODS

Animals used during this study were cared for in accordance with University of Illinois Animal Care and Use Committee guidelines. Pigs were humanely slaughtered at a federally inspected processing facility and carcasses transported to the University of Illinois for further data collection.

Animals and Housing

One hundred eighty pigs (Genetiporc G-performer sires × Fertilis 25 dams; Genetiporc, Alexandria, MN) were used during the live phase of this study. At birth, male pigs within a litter were randomly allotted to one of two castration methods: 1) to be physically castrated (PC) or 2) to be immunologically castrated (IC). Pigs in the PC group were physically castrated according to US production guidelines at 5 ± 2 d of age. Intact males in the IC group were

immunologically castrated by administering one dose (2 mL; subcutaneous into the post-auricular region of the neck) of Improvest (gonadotropin releasing factor analog diphtheria toxoid conjugate, 0.2 mg/mL; Zoetis, Kalamazoo, MI) at 16 wk of age and another 2 mL dose at 20 wk of age. Improvest dosages were administered by trained Improvest personnel. Prior to finishing, gilts that were approximately the same weight as PC pigs were selected to further evaluate diet effects on carcass characteristics and cutting yields. Prior to allotment in the finishing barn, pigs within each sex category were individually weighed and assigned to pens so that pen means within each sex category were equal. Within each group, pens were randomly assigned to RAC finishing diet treatments where the feeding level was 0 mg/kg (control), 5 mg/kg, or 7.5 mg/kg RAC initiated 7 d after second Improvest dose and fed for the last 26 d of finishing. Each pen contained 4 pigs, and the final allotment consisted of 45 pens (n = 5 pens for each sex × RAC level combination) with a floor space of 1.15 m^2/pig, a single-space feeder and one nipple-type water drinker per pen. The finishing barn was mechanically ventilated with part-hard, part-slatted concrete floors.

Diets

Prior to finishing, all pigs were fed the same grower diet program where diets were formulated to meet or exceed NRC (1998) nutrient requirements for intact male pigs. Similarly, finishing diets were formulated to meet the nutrient requirements for intact males fed 7.5 mg/kg RAC (Table 2.1). Ractopamine was fed at the expense of corn and all diets contained equal amounts of crude protein and SID lysine.

Slaughter and Carcass Collection

At the conclusion of the finishing phase, pigs were individually weighed and the two pigs closest to the pen mean were identified and tattooed on the shoulder, loin, and ham for identification in the plant. Pigs (n=177) were loaded onto commercial trucks and transported

(901 km) to a federally inspected slaughter facility. Pigs were held overnight with access to water before being slaughtered according to industry standards using carbon dioxide stunning. Hot carcass weights were collected following slaughter and carcasses spray chilled (-2°C) for approximately 20 h. Following chilling, left sides of carcasses previously identified for carcass cutting yields and meat quality evaluations were selected. Shoulders were removed by making a straight cut between the 2nd and 3rd ribs. Hams were separated from loins and bellies by making a straight cut just anterior to the aitch bone. Shoulders, loin and belly sections, and hams were packaged and transported under refrigeration to the University of Illinois Meat Science Lab for further data collection.

Carcass Characteristics and Loin Quality

Upon arrival, primals were unloaded and stored under refrigeration (2°C) prior to fabrication. Loins were separated from bellies by making a straight cut just ventral to the psoas major on the ham end and approximately 3.8 cm ventral to the backbone on the blade end. Bone-in loins were then cut perpendicular to the length of the loin between the 10th and 11th ribs to expose the LM face. All yield and loin quality measurements were collected on the 11th rib face of loins. Fat thicknesses were obtained at a point halfway around the LM and outlines of LM were then traced onto transparent paper for LM area determination. Loin muscle area was determined by tracing the outlined LM with a planimeter (Super Planix α Planimeter, Tamaya Technics Inc., Tokyo, Japan). Ultimate pH was measured using a pH star probe equipped with a glass electrode (SFK Technologies Inc., Cedar Rapids, IA; calibrated at 2 points, pH 4 and 7). Objective CIE *L**, *a**, and *b** (CIE, 1978) were collected with a Minolta CR-400 Chroma meter (Minolta Camera Company, Osaka, Japan) using a D65 illuminant, a 0° observer, an 8 mm aperture, and a Minolta DP-400 Data Processor calibrated to a white tile of known values.

Subjective color and marbling scores (NPPC, 1999) and firmness scores (NPPC, 1991) were conducted by a single individual according to standards of the National Pork Producers Council.

Carcass Fabrication

Carcasses were fabricated according to guidelines of the Institutional Meat Purchasing Specifications (**IMPS**) as described by the North American Meat Processors Association (NAMP, 2007). Weights were collected on each primal piece prior to fabrication and subprimal cuts following fabrication. Carcass cutout data were also expressed as a percentage of chilled side weight (CSW) by dividing the cut by the CSW.

Jowls, feet, and neckbones were removed from whole shoulders to yield IMPS#403 pork shoulders. Shoulders were skinned and fat removed to yield IMPS#404 skinned shoulders. Boston butts were separated from picnics to yield IMPS#406 bone-in Boston butts and IMPS#405 bone-in picnic shoulders. Bones were removed to yield IMPS#406A boneless Boston butts and IMPS#405A boneless picnic shoulders. Boneless picnic shoulders were further fabricated to yield IMPS#405B cushions (*triceps brachii*).

Skin-on bone-in loins were skinned and fat trimmed to yield IMPS#410 bone-in loins. Trimmed loins were further fabricated to yield IMPS#414 Canadian backs, IMPS#415A tenderloins (side muscle off), IMPS#410A purchaser specified option 1 boneless sirloins, and IMPS#422 backribs. Identities of Canadian back loins were retained for later evaluation of quality attributes.

Feet were removed from hams to produce IMPS#401 hams and designated as whole hams. Whole hams were skinned and excess fat removed for determination of trimmed ham weight. Trimmed hams were fabricated to yield IMPS#402F inside hams, IMPS#402E outsides, IMPS#402H knuckles, and light butts. Whole spareribs-in bellies were fabricated to yield IMPS#408 bellies and IMPS#416 spareribs. Teat lines were removed and flank ends squared to

produce squared bellies. Identities of bellies were retained for later evaluation of fresh belly quality.

Cutting Yields

Boneless lean cutting yields were calculated using the following equation: Boneless lean cutting yield = [(boneless Boston butt + boneless picnic + Canadian back + tenderloin + sirloin + light butt + knuckle + inside ham + outside ham) / CSW] × 100. Bone-in lean cutting yields were calculated using the following equation: Bone-in lean yield = [(trimmed Boston butt + trimmed picnic + trimmed loin + trimmed ham) / CSW] × 100. Carcass cutting yields were calculated using the following equation: Carcass cutting yield = [(components from bone-in lean yield + squared belly) / CSW] × 100.

Loin Sample Collection

Following fabrication, a chop (2.54 cm) was obtained just posterior to the 11th rib face for moisture and lipid content determination. Chops were removed of all external fat, homogenized in a food processor (Cuisinart model CUI DFP-7BC, Cuisinart, East Windsor, NJ), and duplicate 10 g samples of tissue were oven dried at 110° C for approximately 24 h. Dried samples were washed multiple times in an mixture of warm chloroform:methanol (4:1) as described by Novakofski et al. (1989) to determine total extractable lipid. Drip loss was determined by obtaining and suspending a 1.27 cm-thick chop from a fish hook inside a Whirl-Pak bag for approximately 24 h at 2˚C. Weights were obtained just prior to and immediately following chilling. Drip loss was reported as the amount of moisture lost as a percentage of the initial weight.

Fresh Belly Characteristics

Twenty-four hours prior to evaluation, trimmed and squared bellies were placed on tables, covered with polyvinyl film, and chilled (2˚C). Characteristics measured included length,

width, thickness, and firmness. Length and width were measured with a ruler at the midpoint of the cross-sectional and longitudinal axis, respectively. Thickness was measured at 8 locations on the belly using a stainless steel probe. Measurements 1 through 4 were equally spaced and obtained on the dorsal half of the belly starting at the anterior end and working to the posterior end. Measurements 5 through 8 were obtained similarly to measurements 1 through 4 but on the ventral half of the belly. Belly firmness was determined by using the flop method where bellies were draped over a stationary bar skin side down perpendicular to the length of the belly. One measurement was taken between the two skin edges.

Fatty Acid Analysis

A sample of subcutaneous fat tissue comprised of all three layers was obtained from the anterior dorsal corner of each fresh belly for fatty acid analysis. Initially, samples free of lean tissue and skin were cut into pieces. Pieces were frozen in liquid nitrogen before being pulverized in a blender (Warin Products, Torrington, CT) for 10 s. The resulting powder was collected and used to obtain fatty acid methyl esters (FAME) according to the methodology described by AOCS official method Ce 2-66 (1998). Subsequently, FAME were analyzed using a gas chromatograph (Hewlett Packard 5890 series II) equipped with an auto-sampler and a DB-wax capillary column (30 m x 0.25mm x 0. 25 µm film coating, Agilent Technologies, Santa Clara, CA). The equipment was operated under a constant pressure at 1.30 Kg/cm^2 using helium as the carrier gas and a 99:1 split ratio. Temperatures of the injector and of the flame-ionization detector were held constant at 250^0C and 260^0C, respectively. The oven was operated at 170°C for 2 min (programmed temperature to increase 4^0C /min up to 240°C and then held constant for 12.5 min). Chromatographs from FAME were integrated using Agilent Chemstation software for gas chromatograph systems (Version B.01.02, ®Agilent Technologies, Inc.). Peaks were identified using a gas chromatograph reference standard (GLC 68 from Nu-check-prep, Elysian,

Mn). Fatty acids were normalized so that the area of each peak was represented as a percentage of the total area. Iodine values (IV) were calculated using fatty acid profile data with the following AOCS (1998) equation: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.785).

Statistical Analysis

Data were analyzed using the MIXED procedure in SAS (SAS Inst., Cary, NC) and carcass served as the experimental unit for all analyses. Data were analyzed as a randomized complete block design and the model included the fixed effects of sex (PC, IC, gilt), RAC level (0, 5, and 7.5 mg/kg), and their interaction. Replication served as a random variable in all models. Least squares means were generated using LSMEANS and comparisons made using the PDIFF option. Single degree of freedom contrast statements were used to evaluate differences between control diet response and the overall RAC response. In the case of a significant interaction between sex and RAC feeding level, single degree of freedom contrasts statements were used to further evaluate the effects of RAC feeding within each sex category. To protect against error associated with multiple comparisons, confidence intervals for interaction means were adjusted using the Tukey-Kramer method. Normality of residuals was checked using the CAPABILITY procedure and outliers were left in the data set unless deemed physiologically impossible. Homogeneity of variances was tested using the Levene's test or the Brown and Forsythe's test in the case of non-normal data using the GLM procedure in SAS. Effects were deemed significant at $P < 0.05$ and tendencies were reported if $0.05 \leq P \leq 0.10$.

RESULTS

Carcass Characteristics and Loin Quality

There were no significant interactions between sex and RAC feeding level for effects on any carcass characteristics and loin quality characteristics evaluated in this study (Table 2.2).

When pooled together, RAC-fed (5 and 7.5 mg/kg RAC) carcasses were 1.16 kg heavier (P = 0.03) than control-fed (0 mg/kg RAC) carcasses. Control-fed loins had greater ($P < 0.01$) a* values than RAC-fed loins. However, RAC feeding did not affect carcass fat depths ($P = 0.81$), LM area ($P = 0.39$), pH ($P = 0.15$), color scores ($P = 0.16$), marbling scores ($P = 0.97$), firmness scores ($P = 0.44$), L* values ($P = 0.39$), b* values ($P = 0.16$), drip losses ($P = 0.45$), and lipid content ($P = 0.14$).

For carcass weights, IC carcasses (104.83 kg) and PC carcasses (102.24 kg) were heavier ($P \leq 0.03$) than gilt carcasses (96.52 kg) while there were no differences ($P = 0.30$) between PC and IC carcass weights. For backfat, PC carcasses had 0.41 cm more ($P < 0.01$) backfat than IC carcasses which had 0.37 cm more ($P < 0.01$) backfat than gilt carcasses. When evaluating loin quality, PC loins were darker ($P < 0.05$) than IC loins with gilt loins not being different ($P \geq 0.19$) than either other sex. Additionally, PC loins had 0.47 units greater ($P < 0.01$) LM marbling scores and 0.52 percentage units greater ($P < 0.01$) lipid than IC loins; however, IC and gilt loins were similar ($P \geq 0.42$) in terms of marbling and lipid content. For loin b*, IC loins had greater ($P < 0.05$) values than PC loins while gilt loins were not different ($P \geq 0.19$) from either other sex. Furthermore, IC loins had 0.64 percentage units greater ($P = 0.04$) drip loss values than PC loins while gilt loins were not different ($P \geq 0.16$) from either other sex. Sex did not affect LM area ($P = 0.45$), pH ($P = 0.40$), firmness scores ($P = 0.81$), L* values ($P = 0.66$), and a* values ($P = 0.32$) in the present study.

Carcass Cutting Yields

There were no significant interactions between sex and RAC feeding level for effects on any cutting yields of components from shoulders in this study (Table 2.3). Bone-in Boston butts from RAC-fed carcasses were heavier ($P < 0.01$) than those from control-fed carcasses. However, RAC feeding did not affect shoulder ($P = 0.34$), boneless Boston butt ($P \geq 0.14$),

bone-in and boneless picnic ($P \geq 0.54$), cushion ($P \geq 0.81$), and jowl ($P \geq 0.35$) cutting yields. Shoulders from IC carcasses were heavier ($P = 0.01$) and made up a greater ($P < 0.05$) percentage of chilled side weight than those from gilt carcasses while PC shoulders were not different ($P \geq 0.12$) from either other sex on a weight basis or as percentage of chilled side weight. Boneless Boston butts from IC carcasses were heavier ($P = 0.01$) than those from gilt carcasses while boneless Boston butts from PC carcasses were similar ($P \geq 0.12$) in weight to those from other sexes. Bone-in picnics from IC carcasses were heavier ($P \leq 0.02$) than those from both gilt and PC carcasses while picnics from gilt and PC carcasses were similar ($P = 0.16$) in weight. Bone-in picnics from IC carcasses represented a greater ($P = 0.02$) percentage of chilled side weight than those from PC carcasses while picnics from gilt carcasses represented a similar ($P > 0.05$) percentage of chilled side weight as those from the other sexes. Cushions from IC carcasses were heavier ($P = 0.02$) than those from PC carcasses while cushions from gilt carcasses were similar ($P \geq 0.15$) in weight to those from the other sexes. Cushions from gilt carcasses represented a greater ($P = 0.02$) percentage of chilled side weight than those from PC carcasses while cushions from IC carcasses represented a similar ($P \geq 0.12$) percentage of chilled side weight as those from the other sexes. Sex did not affect bone-in Boston butt ($P \geq 0.17$) and jowl ($P \geq 0.13$) cutting yields.

There were interactions ($P \leq 0.02$) between sex and RAC feeding for effects on whole loins and trimmed loins when expressed as a percentage of chilled side weight in this study (Figure 2.1). For whole loins, feeding RAC increased ($P = 0.04$) gilt carcass whole loin yields while tending ($P = 0.08$) to decrease yields in IC carcasses. Feeding RAC had no effect ($P = 0.28$) on whole loin yields in PC carcasses. For trimmed loins, feeding RAC tended ($P = 0.05$)

to increase PC carcass trimmed loin yields while having no effects ($P \geq 0.10$) on gilt and IC carcass trimmed loin yields.

Trimmed loins, Canadian backs, and tenderloins from RAC-fed carcasses were heavier ($P \leq 0.03$) than those from control-fed carcasses; however, RAC feeding did not affect ($P \geq 0.18$) sirloin cutting yields (Table 2.4). Whole loins from PC and IC carcasses were heavier ($P = 0.01$) than those from gilt carcasses while loins from PC and IC carcasses had similar ($P = 0.89$) weights. Canadian backs from gilt carcasses represented a greater ($P < 0.01$) percentage of chilled side weight than those from IC carcasses which represented a greater ($P < 0.05$) percentage of chilled side weight than those from PC carcasses. Sex did not affect tenderloin ($P \geq 0.24$) and sirloin ($P \geq 0.14$) cutting yields.

Although, there were no significant interactions between sex and diet for effects on ham cutting yields, there tended ($P = 0.08$) to be an interaction for whole ham weights (Table 2.5). However, feeding RAC did not have an effect ($P \geq 0.16$) on whole hams from any sex category. Additionally, feeding RAC did not affect ($P \geq 0.38$) any other ham component cutting yields. Whole hams from gilt carcasses represented a greater ($P = 0.02$) percentage of chilled side weight than those from IC carcasses while hams from PC carcasses represented similar ($P \geq 0.17$) percentages of chilled side weights as the other sexes. Additionally, trimmed hams from gilt carcasses represented a greater ($P \leq 0.03$) percentage of chilled side weight than those from both PC and IC carcasses while hams from PC and IC carcasses represented similar ($P = 0.66$) percentages of chilled side weights. Inside hams from IC carcasses were heavier ($P = 0.04$) than those from gilt carcasses and tended ($P = 0.07$) to be heavier than those from PC carcasses while inside hams from gilt and PC carcasses were similar in weight ($P = 0.78$). Outside hams and knuckles from gilt carcasses represented a greater ($P \leq 0.02$) percentage of chilled side weight

than those from both PC and IC carcasses while there were no differences ($P \geq 0.78$) between outsides and knuckles from PC and IC carcasses when expressed as a percentage of chilled side weight. Sex did not affect ($P \geq 0.33$) light butt cutting yields.

There were no significant interactions between sex and RAC feeding on belly cutting yields in this study (Table 2.6). Squared bellies from RAC-fed carcasses were heavier ($P = 0.02$) than those from control-fed carcasses. However, RAC feeding did not affect ($P \geq 0.14$) whole belly, spareribs, and natural fall belly cutting yields. Sex did not affect ($P \geq 0.14$) belly component cutting yields.

There were no significant interactions between sex and RAC feeding level on overall carcass cutting yields (Table 2.7). Feeding RAC did not affect ($P = 0.49$) boneless lean cutting yields; however, RAC-fed carcasses tended ($P = 0.09$) to have greater bone-in lean cutting yields than control-fed carcasses. Additionally, RAC-fed carcasses had 1.19 percentage units greater ($P = 0.03$) total carcass cutting yields than control-fed carcasses. Boneless lean cutting yields for gilt carcasses (40.80%) and IC carcasses (40.29%) were greater ($P \leq 0.04$) than those for PC carcasses (38.90%) while there were no differences ($P = 0.43$) between gilt and IC carcasses. Bone-in lean cutting yields for IC carcasses (53.37%) were greater ($P = 0.01$) than those for PC carcasses (51.80%). Gilt carcasses (52.92%) tended ($P = 0.08$) to have greater bone-in lean yields than PC carcasses while being similar ($P = 0.47$) to those of IC carcasses. Sex did not affect ($P = 0.16$) total carcass cutting yields.

Fresh Belly Characteristics

There were no significant interactions between sex and RAC feeding level for fresh belly characteristics in this study (Table 2.8). Feeding RAC did not affect belly length ($P = 0.22$), belly width ($P = 0.52$), belly thickness ($P = 0.70$), belly firmness ($P = 0.32$), or belly iodine values ($P = 0.61$). Bellies from PC carcasses were 0.34 cm thicker ($P = 0.02$) than those from IC

carcasses which were 0.29 cm thicker ($P = 0.04$) than those from gilt carcasses. When evaluating belly firmness, bellies from PC carcasses had 12.03 and 14.54 cm greater ($P \leq 0.001$) flop distances (i.e., were firmer) than bellies from both gilt and IC carcasses, respectively, while there were no differences ($P = 0.27$) between flop distances of bellies from gilt and IC carcasses. However, bellies from gilt carcasses had 2.54 and 3.41 units greater ($P \leq 0.03$) iodine values than bellies from PC and IC carcasses, respectively, while there were no differences ($P = 0.42$) between belly iodine values from PC carcasses and those from IC carcasses. Sex did not affect belly length ($P = 0.31$) or belly width ($P = 0.15$).

DISCUSSION

The lack of interactions between immunological castration and feeding RAC in the present study supports the concept drawn from previous research that these technologies when used together are additive in terms of improving carcass characteristics and cutting yields while having little to no impact on fresh pork quality (Moore et al., 2009; Rikard-Bell et al., 2009). This is evident due to RAC improving carcass characteristics and cutting yields regardless of sex in the present study. It is important to note that pigs in the present study were fed similar diets in terms of energy, protein content, and amino acid levels where the only differences between diet was the addition of RAC. These diets made available adequate or excess nutrients required to deposit lean tissue and may not be typically seen in commercial swine operations where amino acid levels are reduced to optimize profitability (Apple et al., 2004).

The increased carcass weights and carcass cutting yields coupled with minimal effects on loin quality seen in the present study agree with previous studies (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004; Rincker et al., 2005; See et al., 2005; Apple et al., 2007b; Fernández-Dueñas et al., 2008; Carr et al., 2009; Patience et al., 2009; Leick

et al., 2010; Kutzler et al., 2011; Hinson et al., 2012ab; Bohrer et al., 2013). These increases in carcass leanness and carcass cutability are expected due to the increased protein synthesis and lean accretion often associated with RAC feeding (Adeola et al., 1992; Crome et al., 1996; Mersmann, 1998). It has been reported that RAC feeding decreases the quantity of saturated fatty acids (Engeseth et al., 1992; Perkins et al., 1992; Apple et al., 2007a) and increases the polyunsaturation of pork fat (Carr et al., 2005; Weber et al., 2006). However, RAC feeding in the present study had no impact on any belly characteristics similar to the findings of others who reported no differences between control-fed and RAC-fed bellies when evaluating belly length, width, thickness, and trimmed weight (Stites et al., 1991; Leick et al., 2010), or belly firmness (Carr et al., 2005; Scramlin et al., 2008; Leick et al., 2010). It is important to note that the pigs in the present study were much heavier than pigs used in other studies evaluating RAC effects on fresh belly characteristics and that pigs in the present study may have already deposited sufficient quantities of fat in the belly area. With the understanding that RAC feeding slows lipogenesis; however, there were no differences in backfat depths between control-fed and RAC-fed carcasses in the present study indicating that RAC had little effects on lipogenesis. Furthermore, the pigs in the present study were fed diets that were adequate in terms of the nutrients required to deposit ample amounts of lean tissue and this may have had an impact on overall fat deposition which ultimately demonstrated no effects of RAC feeding on belly quality.

The findings in the present study where IC carcasses had less fat and increased cutting yields are comparable to the results of others (Pauley et al., 2009; Boler et al., 2011; Boler et al., 2012). These changes in carcass composition are expected as IC pigs spend the majority of production as boars which characteristically have a greater lean deposition and reduced fat deposition when compared to PC pigs (Dunshea et al., 2001; Morales et al., 2011). This change

in composition is also evident when evaluating LM lipid content where PC loins regularly have more lipid than IC loins (Boler et al., 2012). The effects of immunological castration on belly quality have been attributed to IC carcasses having lower monounsaturated fatty acid concentrations, greater polyunsaturated fatty acid concentrations, and overall greater iodine values when compared to PC carcasses (Boler et al., 2012). Contrary to the findings of Boler et al. (2012), there were no differences between belly fat iodine values of PC and IC carcasses in the present study. The changes in belly firmness seen in the present study are most likely a result of the changes in belly thickness and not so much a result of change in iodine value.

In conclusion, both immunological castration and feeding ractopamine improved carcass characteristics and carcass cutting yields while having minimal to no effects on fresh pork quality. Furthermore, the two technologies are additive and only further improve carcass characteristics and cutting yields when used together. While bellies from immunologically castrated carcasses were softer than those from physically castrated carcasses, there were no differences between belly iodine values of physically and immunologically castrated carcasses.

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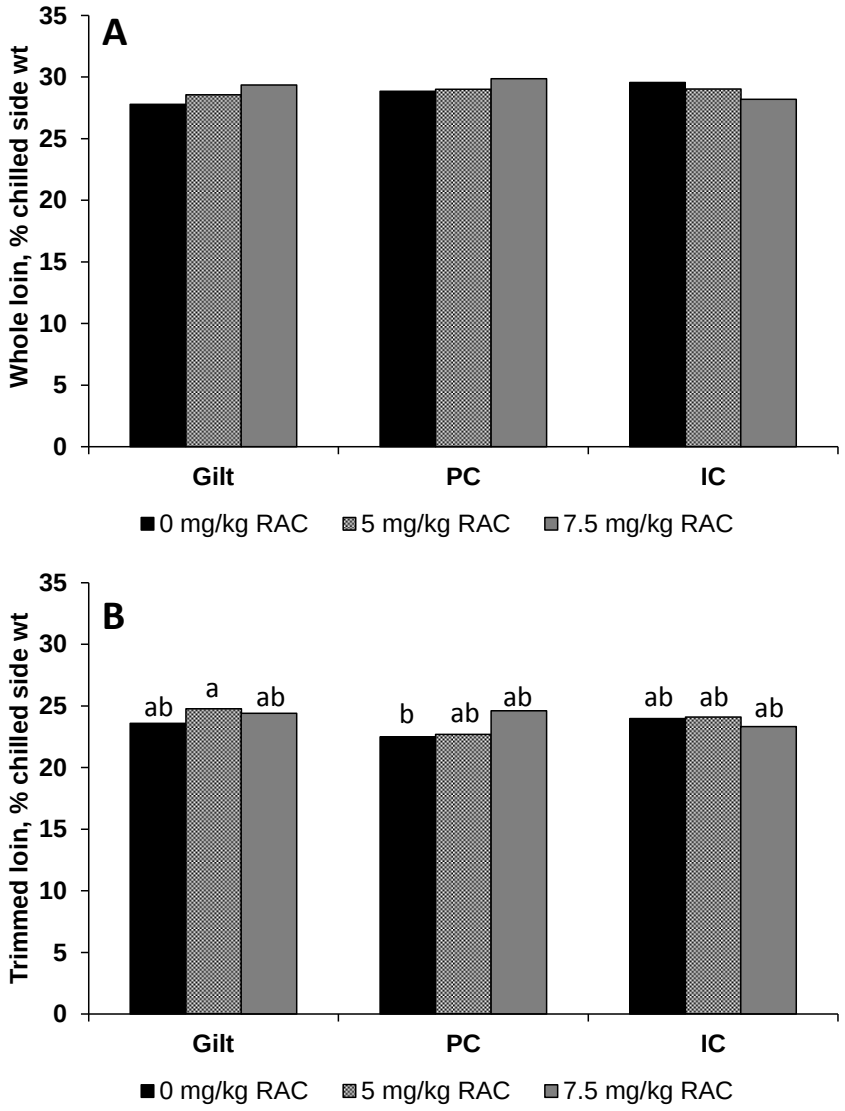
FIGURES

Figure 2.1. Interactive effects of feeding ractopamine (RAC, Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, or immunologically castrated (IC; Improvest, Zoetis, Kalamazoo, MI) pigs on whole loin (A) and trimmed loin cutability (B) expressed as a percentage of chilled side weight (CSW). [a, b] Means lacking common superscripts differ ($P < 0.05$)



TABLES

Table 2. 1. Ingredients and calculated composition of ractopamine (RAC; Elanco Animal Health, Greenfield, IN) finishing diets fed to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on an as-fed basis.[1,2]

	RAC level, mg/kg		
	0	5	7.5
Ingredient, %			
Corn	71.02	71.00	70.99
Soybean meal	27.20	27.20	27.20
Limestone	0.68	0.68	0.68
Monocal 21%	0.29	0.29	0.29
Salt	0.46	0.46	0.46
Lysine	0.15	0.15	0.15
Alimet	0.05	0.05	0.05
Trace mineral[3]	0.08	0.08	0.08
Threonine	0.05	0.05	0.05
Vitamins[4]	0.03	0.03	0.03
Optiphos 2000	0.01	0.01	0.01
Paylean 9	-	0.03	0.04
Composition			
NRC ME, Kcal/kg	3317	3317	3317
CP, %	18.14	18.14	18.14
Ca, %	0.45	0.45	0.45
Available P, %	0.18	0.18	0.18
Total Lys, %	1.11	1.11	1.11
SID Lys, %	0.98	0.98	0.98
SID Met+Cys:Lys	0.57	0.57	0.57
SID Trp:Lys	0.20	0.20	0.20
SID Thr:Lys	0.64	0.64	0.64
SID Ile:Lys	0.68	0.68	0.68
SID Val:Lys	0.76	0.76	0.76

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.
[2] Diets formulated to meet or exceed NRC (1998) requirements.
[3] Provided per kg of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.
[4] Provided per kg of final diet: vitamin A, 4,410 IU; vitamin D3, 689 IU; vitamin E, 22.1 IU; riboflavin, 4.96 mg; vitamin B12, 0.02 mg; menadione, 1.27 mg; D-pantothenic acid, 17.9 mg; and niacin, 20.9 mg.

Table 2.2. Effects of feeding ractopamine (RAC; Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on carcass characteristics and loin quality.[1]

	Sex				RAC level, mg/kg				*P*-values[2]			
Item	Gilt	PC	IC	SEM	0	5	7.5	SEM	Sex	RAC	Sex × RAC	0 vs RAC
HCW, kg	96.52^{b}	102.24^{a}	104.83^{a}	1.68	99.43^{b}	102.34^{a}	101.82^{ab}	1.26	0.01	0.07	0.95	0.03
Backfat depth, cm	2.01^{c}	2.79^{a}	2.38^{b}	0.11	2.40	2.34	2.43	0.11	< 0.01	0.81	0.37	0.92
LM area, sq. cm	57.70	55.93	57.42	1.06	56.16	56.73	58.16	1.05	0.45	0.39	0.50	0.32
pH	5.58	5.61	5.59	0.03	5.57	5.62	5.59	0.03	0.40	0.15	0.78	0.12
Color[3]	3.77^{ab}	3.86^{a}	3.60^{b}	0.10	3.80	3.82	3.60	0.10	0.13	0.16	0.38	0.41
Marbling[3]	1.77^{b}	2.37^{a}	1.90^{b}	0.14	1.99	2.01	2.03	0.14	< 0.01	0.97	0.94	0.83
Firmness[3]	2.47	2.58	2.47	0.15	2.42	2.45	2.63	0.13	0.81	0.44	0.75	0.43
L*[4]	48.09	48.37	48.74	1.00	48.04	48.30	48.87	0.98	0.66	0.39	0.95	0.31
a*[4]	6.96	7.38	6.98	0.34	7.73^{a}	6.72^{b}	6.88^{b}	0.34	0.32	< 0.01	0.86	< 0.01
b*[4]	3.77^{ab}	3.86^{a}	3.60^{b}	0.10	3.80	3.82	3.60	0.10	0.13	0.16	0.38	0.41
Drip loss, %	2.74^{ab}	2.30^{b}	2.94^{a}	0.30	2.96	2.55	2.48	0.33	0.12	0.45	0.84	0.23
LM lipid, %	1.73^{b}	2.34^{a}	1.82^{b}	0.13	2.10^{a}	1.80^{b}	1.98^{ab}	0.13	< 0.01	0.14	0.88	0.10

$^{a, b, c}$ Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.

[2] Single degree of freedom contrasts used to determine effects of feeding RAC: 0 (control) vs RAC (5 and 7.5 mg/kg).

[3] Evaluated according to the National Pork Producers Council standards for color and marbling (NPPC, 1999) and firmness (NPPC, 1991).

[4] *L** = lightness; *a** = redness; *b** = yellowness

Table 2.3. Effects of feeding ractopamine (RAC; Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on left side carcass cut-out values from the shoulder.[1]

	Sex				RAC level, mg/kg				*P*-values[2]			
Item	Gilt	PC	IC	SEM	0	5	7.5	SEM	Sex	RAC	Sex × RAC	0 vs RAC
Shoulder, kg	9.62[b]	10.25[ab]	10.80[a]	0.27	10.07	10.33	10.26	0.19	0.03	0.34	0.81	0.16
% chilled side wt	20.38[b]	20.60[ab]	21.20[a]	0.41	20.48	20.64	21.07	0.41	0.12	0.34	0.55	0.29
Bone-in Boston, kg	3.71	3.83	4.09	0.13	3.73[b]	3.98[a]	3.92[a]	0.10	0.17	0.03	0.79	< 0.01
% chilled side wt	7.86	7.69	8.05	0.19	7.59	7.95	8.06	0.20	0.21	0.17	0.49	0.08
Boneless Boston, kg	9.62[b]	10.25[ab]	10.80[a]	0.27	10.07	10.33	10.26	0.19	0.03	0.34	0.81	0.16
% chilled side wt	7.24	7.07	7.43	0.17	6.96	7.33	7.45	0.18	0.15	0.14	0.29	0.06
Bone-in picnic, kg	5.00[b]	5.22[b]	5.62[a]	0.10	5.24	5.31	5.28	0.09	< 0.01	0.79	0.70	0.54
% chilled side wt	10.59[ab]	10.50[b]	11.05[a]	0.17	10.68	10.62	10.84	0.17	0.05	0.65	0.66	0.81
Boneless picnic, kg	3.74[b]	3.91[b]	4.22[a]	0.09	3.90	4.01	3.95	0.08	< 0.01	0.54	0.58	0.36
% chilled side wt	7.91	7.87	8.29	0.15	7.95	8.02	8.10	0.16	0.08	0.76	0.51	0.54
Cushion, kg	0.94[ab]	0.91[b]	0.98[a]	0.02	0.93	0.95	0.95	0.02	0.05	0.85	0.09	0.57
% chilled side wt	1.99[a]	1.83[b]	1.93[ab]	0.05	1.90	1.90	1.94	0.05	0.07	0.81	0.10	0.73
Jowl, kg	1.33	1.53	1.45	0.09	1.39	1.43	1.48	0.09	0.13	0.49	0.25	0.31
% chilled side wt	2.81	3.09	2.84	0.18	2.82	2.87	3.05	0.18	0.22	0.35	0.45	0.32

[a, b] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.

[2] Single degree of freedom contrasts used to determine effects of feeding RAC: 0 (control) vs RAC (5 and 7.5 mg/kg).

Table 2.4. Effects of feeding ractopamine (RAC; Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on left side carcass cut-out values from the loin.[1]

	Sex				RAC level, mg/kg				*P*-values[2]			
Item	Gilt	PC	IC	SEM	0	5	7.5	SEM	Sex	RAC	Sex × RAC	0 vs RAC
Whole loin, kg	13.68[b]	14.78[a]	14.73[a]	0.25	14.13	14.44	14.60	0.23	0.02	0.28	0.15	0.13
% chilled side wt	28.57	29.24	28.93	0.28	28.73	28.87	29.13	0.30	0.18	0.59	0.01	0.43
Trimmed loin, kg	11.61	11.58	12.11	0.21	11.47[b]	11.91[a]	11.91[a]	0.18	0.19	0.08	0.18	0.02
% chilled side wt	24.25[a]	23.25[b]	23.80[ab]	0.30	23.35	23.84	24.11	0.31	0.05	0.15	0.02	0.07
Canadian back, kg	4.32	4.06	4.33	0.09	4.13[b]	4.32[a]	4.25[ab]	0.07	0.09	0.07	0.39	0.03
% chilled side wt	9.02[a]	8.16[c]	8.53[b]	0.14	8.41	8.66	8.63	0.15	< 0.01	0.44	0.19	0.22
Tenderloin, kg	0.52	0.52	0.56	0.02	0.51[b]	0.55[a]	0.54[ab]	0.02	0.24	0.04	0.42	0.01
% chilled side wt	1.09	1.04	1.10	0.03	1.03	1.10	1.10	0.03	0.28	0.11	0.35	0.04
Sirloin, kg	0.92	0.85	0.93	0.04	0.85	0.93	0.92	0.04	0.34	0.18	0.47	0.08
% chilled side wt	1.90	1.71	1.84	0.07	1.73	1.86	1.85	0.07	0.14	0.40	0.36	0.18

[a, b, c] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.

[2] Single degree of freedom contrasts used to determine effects of feeding RAC: 0 (control) vs RAC (5 and 7.5 mg/kg).

Table 2.5. Effects of feeding ractopamine (RAC; Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on left side carcass cut-out values from the ham.[1]

	Sex				RAC level, mg/kg				*P*-values[2]			
Item	Gilt	PC	IC	SEM	0	5	7.5	SEM	Sex	RAC	Sex × RAC	0 vs RAC
Whole ham, kg	12.12	12.32	12.14	0.17	12.21	12.18	12.18	0.16	0.64	0.98	0.08	0.86
% chilled side wt	25.74[a]	24.78[ab]	23.88[b]	0.45	24.90	24.40	25.09	0.42	0.05	0.41	0.55	0.73
Trimmed ham, kg	10.45	10.36	10.47	0.15	10.46	10.38	10.44	0.14	0.85	0.91	0.16	0.78
% chilled side wt	22.19[a]	20.85[b]	20.61[b]	0.37	21.33	20.80	21.52	0.37	0.02	0.38	0.73	0.71
Inside, kg	1.92[b]	1.93[ab]	2.05[a]	0.04	1.97	1.94	1.98	0.04	0.08	0.79	0.35	0.81
% chilled side wt	4.08	3.90	4.03	0.10	4.02	3.90	4.09	0.10	0.50	0.38	0.60	0.80
Outside, kg	2.83	2.78	2.82	0.06	2.81	2.82	2.80	0.06	0.81	0.98	0.78	0.98
% chilled side wt	6.01[a]	5.59[b]	5.55[b]	0.12	5.73	5.64	5.77	0.13	0.02	0.77	0.96	0.86
Knuckle, kg	1.52	1.43	1.47	0.03	1.49	1.46	1.47	0.03	0.16	0.74	0.72	0.45
% chilled side wt	3.22[a]	2.87[b]	2.90[b]	0.07	3.05	2.92	3.03	0.07	< 0.01	0.43	0.83	0.42
Light butt, kg	0.34	0.35	0.32	0.03	0.33	0.35	0.33	0.02	0.57	0.83	0.23	0.79
% chilled side wt	0.72	0.71	0.62	0.05	0.68	0.69	0.68	0.05	0.33	0.94	0.29	0.90

[a, b] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.

[2] Single degree of freedom contrasts used to determine effects of feeding RAC: 0 (control) vs RAC (5 and 7.5 mg/kg).

Table 2.6. Effects of feeding ractopamine (RAC; Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on left side carcass cut-out values from the belly.[1]

	Sex				RAC level, mg/kg				*P*-values[2]			
Item	Gilt	PC	IC	SEM	0	5	7.5	SEM	Sex	RAC	Sex × RAC	0 vs RAC
Whole belly, kg	8.53	9.08	9.12	0.29	8.71	9.01	9.00	0.23	0.21	0.14	0.83	0.05
% chilled side wt	18.07	18.23	17.93	0.52	17.71	18.01	18.50	0.51	0.80	0.22	0.51	0.17
Spareribs, kg	1.68	1.69	1.83	0.05	1.71	1.77	1.72	0.04	0.13	0.38	0.25	0.31
% chilled side wt	3.57	3.40	3.59	0.08	3.47	3.53	3.55	0.08	0.18	0.74	0.34	0.45
Natural fall belly, kg	6.85	7.39	7.29	0.25	7.01	7.24	7.28	0.29	0.17	0.16	0.92	0.06
% chilled side wt	14.50	14.83	14.33	0.47	14.24	14.47	14.95	0.47	0.48	0.21	0.57	0.18
Squared belly, kg	4.83	5.23	5.17	0.16	4.90[b]	5.17[a]	5.16[a]	0.13	0.14	0.06	0.84	0.02
% chilled side wt	10.24	10.49	10.17	0.30	9.96	10.32	10.60	0.32	0.52	0.19	0.74	0.10

[a, b] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.

[2] Single degree of freedom contrasts used to determine effects of feeding RAC: 0 (control) vs RAC (5 and 7.5 mg/kg).

Table 2.7. Effects of feeding ractopamine (RAC; Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on boneless lean cutting yields, bone-in lean cutting yields, and total carcass cutting yields.[1]

	Sex				RAC level, mg/kg				*P*-values[2]			
Item	Gilt	PC	IC	SEM	0	5	7.5	SEM	Sex	RAC	Sex × RAC	0 vs RAC
Chilled side wt, kg	47.34[b]	49.97[a]	50.87[a]	0.75	49.14	50.00	49.04	0.66	0.02	0.47	0.98	0.61
Boneless yield, %CSW[3]	40.80[a]	38.90[b]	40.29[a]	0.49	39.57	40.11	40.31	0.50	0.02	0.49	0.20	0.25
Bone-in yield, %CSW[4]	52.92[ab]	51.80[b]	53.37[a]	0.44	52.08	52.78	53.23	0.44	0.04	0.19	0.10	0.09
Carcass yield, %CSW[5]	57.75	57.03	58.53	0.51	56.98[b]	57.95[ab]	58.38[a]	0.47	0.16	0.07	0.12	0.03

[a, b] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.

[2] Single degree of freedom contrasts used to determine effects of feeding RAC: 0 (control) vs RAC (5 and 7.5 mg/kg).

[3] Boneless lean yield = [(boneless Boston butt + boneless picnic + Canadian back + tenderloin + sirloin + light butt + knuckle + inside ham + outside ham) / CSW] × 100

[4] Bone-in lean yield = [(trimmed Boston butt + trimmed picnic + trimmed loin + trimmed ham) / CSW] × 100

[5] Carcass cutting yield = [(components from lean yield + squared belly) / CSW] × 100

Table 2.8. Effects of feeding ractopamine (RAC; Elanco Animal Health, Greenfield, IN) to gilts, physically castrated (PC) pigs, and immunologically castrated (IC) pigs on fresh belly characteristics.[1]

	Sex				RAC level, mg/kg				*P*-values[2]			
Item	Gilt	PC	IC	SEM	0	5	7.5	SEM	Sex	RAC	Sex × RAC	0 vs RAC
Length, cm	58.87	59.26	60.14	0.96	59.20	60.05	59.02	0.92	0.31	0.22	0.62	0.55
Width, cm	22.47	21.10	22.05	0.47	21.57	22.03	22.03	0.37	0.15	0.52	0.11	0.27
Thickness, cm	3.61[c]	4.24[a]	3.90[b]	0.10	3.86	3.92	3.96	0.10	< 0.01	0.70	0.51	0.45
Flop distance, cm	24.99[b]	39.53[a]	27.50[b]	2.29	28.94	31.28	31.80	2.28	< 0.01	0.32	0.48	0.14
Iodine value, g/100g[3]	67.86[a]	64.45[b]	65.31[b]	0.73	65.41	66.33	65.89	0.67	0.02	0.61	0.75	0.39

[a, b] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI), one at 16 wk and an additional dose at 20 wk of age.

[2] Single degree of freedom contrasts used to determine effects of feeding RAC: 0 (control) vs RAC (5 and 7.5 mg/kg).

[3] Iodine value (IV) calculated from fatty acid profiles using the following equation: IV in g/100 g of fat = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.785).

Chapter 3

EFFECTS OF FEEDING RACTOPAMINE HYDROCHLORIDE (PAYLEAN®) TO PHYSICAL AND IMMUNOLOGICAL CASTRATES (IMPROVEST®) IN A COMMERCIAL SETTING ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS

ABSTRACT

Sixty-four pens with 22 pigs per pen were used to evaluate effects of feeding ractopamine (RAC; 5 mg/kg) to physically castrated (PC) and immunologically castrated (IC) pigs on growth performance and carcass characteristics. Male pigs were randomly assigned to castration method at birth and fed the same nursery diets prior to allotment in a grow-finish barn. Pigs in the PC group were physically castrated at 5 d of age, and pigs in the IC group were administered Improvest at 11 and 18 wk of age. Diet treatments (control or RAC) were initiated on d 87 of study and final treatment arrangement was a 2 x 2 factorial of sex and diet. Data were analyzed using PROC MIXED in SAS with fixed effects of sex, diet, market group, and their interaction; pen was experimental unit. From d 0-65, IC pigs had 12% greater (P<0.01) G:F and less (P<0.01) ADFI than PC pigs while having similar (P=0.38) ADG. From d 65-87, IC pigs had 7% greater (P<0.01) ADG and 12% greater (P<0.01) G:F than PC pigs while having similar (P=0.16) ADFI. At the initiation of diet (RAC) treatments, BW of all treatments were similar (P≥0.32). From d 87-120, IC pigs had 10% greater (P<0.01) ADG and 10% greater (P<0.01) ADFI than PC pigs, while having similar (P=0.64) G:F. Feeding RAC increased (P<0.01) ADG and G:F by 17% and 18%, respectively, while having no effect (P=0.42) on ADFI from d 87-120. There were no significant interactions between sex and diet on growth performance from d

87-120. For the entire study (d 0-120), IC pigs had 2% greater (P<0.01) ADG, 4% decreased (P<0.01) ADFI, and 7% greater (P<0.01) G:F than PC pigs. At slaughter, IC pigs were 2.5 kg heavier (P<0.01), had similar (P=0.10) carcass weights, and a 1.8 percentage units less (P<0.01) dressing yields than PC pigs. Additionally, PC carcasses had 1.3 mm more (P<0.01) fat and 1.7 mm deeper (P<0.01) loins than IC pigs. Also, RAC-fed pigs were 2.9 kg heavier (P<0.01) at slaughter, had 2.3 kg heavier (P<0.01) carcasses, had 2.2 mm deeper (P<0.01) loins, and tended (P<0.10) to have 0.4 mm less fat than control-fed pigs while having similar (P=0.21) dressing yields. Group 3 pigs were the heaviest (P<0.01) at slaughter, had the heaviest (P<0.01) carcasses, greatest (P<0.01) dressing yields, and the most (P<0.01) carcass fat of all market groups. Overall, immunological castration and RAC are additive in terms of improving growth performance and carcass characteristics.

Key words: Paylean; Improvest; growth performance; carcass

INTRODUCTION

Ractopamine hydrochloride (RAC), commercially available as Paylean® (Elanco Animal Health, Greenfield, IN), is a β-adrenergic agonist used in finishing swine diets. Feeding low levels (5 mg/kg) of RAC increases ADG and improves feed efficiency of finishing pigs (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004, 2005; Apple et al., 2007; Patience et al., 2009) and improves carcass weights and muscling (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004; See et al., 2005; Apple et al., 2007; Carr et al., 2009; Kutzler et al., 2011). Improvest® (Zoetis, Kalamazoo, MI) is an immunological response product that was developed for the control of boar taint in intact male pigs where the first dose is administered after 9 wk of age and the second dose is administered at least 4 wk after the first. Pigs are marketed at least 3 wk and no greater than 10 wk following second dose.

Immunologically castrated (IC) pigs consistently have greater ADG and improved feed efficiency (Pauly et al., 2009; Morales et al., 2011) when compared to physically castrated (PC) pigs following second dose with Improvest . Despite having decreased dressing percentages (Morales et al., 2011; Boler et al., 2012), IC pigs produce leaner carcasses that have greater cutting yields than PC pigs due to having less carcass fat (Dunshea et al., 2001; Jaros et al., 2005; Pauly et al., 2009; Morales et al., 2011; Boler et al., 2012).

In light weight pigs, feeding RAC and immunological castration are additive in terms of improving growth performance and carcass characteristics. Feeding RAC to IC pigs increased ADG and improved feed efficiency (Rikard-Bell et al., 2009) while improving carcass characteristics (Moore et al., 2009). To date, however, there are no studies which compare RAC feeding of PC to RAC feeding of IC at contemporary heavy weights. Therefore, the objective of this study was to evaluate the effects of feeding RAC to PC and IC pigs in a commercial setting on growth performance and carcass characteristics with conventional market weights for the US pork industry.

MATERIALS AND METHODS

All animals used in this study were cared for in accordance with University of Missouri Animal Care and Use Committee regulations.

Animals and Housing

Sixty-four pens of 22 male pigs (n = 1,408; PIC 337 × C-22 or 1050; Pig Improvement Company, Hendersonville, TN) per pen were used in this study. Pigs were randomly assigned to castration method (PC or IC) at processing (5 ± 4 d of age). Pigs designated for the PC group were surgically castrated according to normal US production techniques within 10 d of birth, whereas those designated for the IC group were left intact. All pigs were weaned and placed in a nursery at 3 wk of age where they were fed the same 3-phase nursery diet until allotment in a

commercial grow-finish research facility at 9 wk of age (d 0 of study) for the duration of the study. Pigs were housed in a commercial environment with fully slatted concrete floors, stainless steel water cups, and a four-hole stainless feeder with 127 cm (5.8 cm/pig) of linear feeder space. Pens were 2.44 m wide and 5.79 m in length providing 14.13 sq. m (0.64 sq. m/pig) of floor space. The finishing barn included two separate rooms with a pen scale, feed room, and office between the rooms. Both rooms had curtain side walls and fans positioned on both ends. Pigs were blocked by room in the barn.

Intact males were immunologically castrated by administering one dose (2 mL; subcutaneous into the post-auricular region of the neck) of Improvest (gonadotropin releasing factor analog diphtheria toxoid conjugate, 0.2 mg/mL; Zoetis, Kalamazoo, MI) at 11 wk of age (d 16 of study) and another 2 mL dose at 18 wk of age (d 65 of study). Improvest dosages were administered by trained Improvest personnel.

Growth performance data were collected at allotment in the grow-finish barn (d 0), second Improvest dose (d 65), start of diet treatment (d 87), and each marketing day (d 99, d 106, and d 120). For BW, pen weights were collected for both blocks. Additionally, individual BW were collected for block 1. For ADFI, feed consumption was monitored and residual feed left in feeders was measured. To account for any pigs that were marketed or may have been removed between weigh days, pig days [(number of pigs per pen per day) × (number of days)] were used to calculate ADG and ADFI on a pen basis.

Diets

Throughout the grower phase, all pigs were fed a step-down lysine program, with IC pigs being fed diets that were approximately 0.1% greater in standardized ileal digestible (SID) lysine than PC pigs until start of diet treatment (d 87; Table 3.1). Feed used during the growing and finishing phases was manufactured at a commercial feed mill and delivered to the research

facility. Feed was available ad libitum, addition of feed was electronically recorded, and feeders were checked twice daily by barn personnel. Diet treatments were assigned at approximately 3 wk post-second injection with Improvest. Diet treatments (Table 3.2) were either a commercial finishing diet (control) or a commercial finishing diet with the addition of ractopamine hydrochloride (Paylean 9, Elanco Animal Health, Greenfield, IN) where the final concentration was 5 mg/kg of diet (RAC). Final treatment arrangement was a 2 × 2 factorial of sex (PC or IC) and diet (control or RAC) with 16 replications of each sex and diet combination. For finishing diets, control-fed physical castrates and control-fed immunological castrates received a diet containing 12.7% crude protein and 0.65% standardized ileal digestible lysine. Whereas RAC-fed PC pigs and RAC-fed IC pigs received a diet containing 17.4% crude protein and 0.95% standardized ileal digestible lysine. Analysis of control and RAC diets were conducted by an off-site lab for determination of dosage accuracy. All samples were within acceptable ranges for required amounts of ractopamine hydrochloride. At each diet change, feed was sampled for each treatment from randomly identified feeders, pooled by treatment, and a subsample submitted for laboratory analysis of nutrients. All nutritional values for diets met or exceeded NRC (1998) requirements.

Slaughter

To follow commercial production practices, pigs were selected for slaughter based on ending live weight and the heaviest pigs in each pen selected and identified. Pigs were marketed at 12 d (4.5 wk after second Improvest dose), 19 d (5.5 wk after second Improvest dose), and 33 d (7.5 wk after second Improvest dose) following the start of final diet treatments. For market group 1 (12 d on diet treatment), pens were standardized to 17 pigs per pen. For market group 2 (19 d on diet treatment), pens were standardized to 9 pigs per pen. All remaining pigs were marketed in group 3 (33 d on diet treatment). For block 1, pigs were selected based on

individual live weights. For block 2, pigs were visually selected by barn personnel. After selection, pigs were tattooed on shoulders and hams for identification in the processing facility. Pigs were loaded onto commercial trucks and transported (263 km) to a federally inspected abattoir where they were held overnight with access to water. Pigs were slaughtered and carcasses chilled according to industry standards. Carcass data including carcass weight, Fat-O-Meater fat depth, LM depth, and estimated percent lean were collected at slaughter by plant personnel.

Statistical Analysis

Data were analyzed using the MIXED procedure in SAS (SAS Inst., Cary, NC), and pen served as experimental unit for all analyses. For growth performance, the model included fixed effects of sex, diet, and their interaction. For carcass characteristics, data were analyzed as a split-plot design with sex and diet combination serving as the whole plot and market group serving as the split plot. Any three-way interactions between sex, diet, and market group were sliced by market group to further distinguish treatment effects. Block, replication, and their interaction served as random variables in all models. Single degree of freedom contrast statements were used to make pair-wise comparisons between treatment groups for any significant interactions. Least squares means and coefficients for single degree of freedom contrast statements were generated using LSMEANS. Normality of residuals was checked using the Capability procedure and outliers were left in the data set unless deemed physiologically impossible. Homogeneity of variance was tested using the Levene's test or the Brown and Forsythe's test in the case of non-normal data using the GLM procedure in SAS. Effects were deemed significant at $P < 0.05$. Trends are noted when $0.05 < P < 0.10$.

RESULTS

Growth Performance

There were no significant interactions between sex and diet for effects on BW in this study. There were no differences ($P = 0.96$) between BW of PC and IC pigs at the start of the study (d 0); however, at second Improvest dose (d 65), PC pigs were 1.05 kg heavier ($P = 0.02$) than IC pigs (Table 3.3). There were no differences ($P = 0.52$) between BW of PC pigs and IC pigs as well as no differences ($P = 0.65$) between control-fed pigs and RAC-fed pigs at the start of diet treatments (d 87). At the completion of the study (d 120), IC pigs were 2.76 kg heavier ($P < 0.01$) than PC pigs. Additionally, RAC-fed pigs were 4.35 kg heavier ($P < 0.0001$) than control-fed pigs at the completion of the study.

There were no significant interactions between sex and diet for effects on ADG in this study. For the first 65 d, PC pigs gained 0.01 kg/d more ($P < 0.01$) than IC pigs; however, IC pigs had greater ($P < 0.0001$) ADG than PC pigs for all other study periods including over the entire study (d 0 to 120; Table 3.3). From second Improvest dose to start of diet treatments (d 65 to 87), IC pigs gained 0.07 kg/d more ($P < 0.0001$) than PC pigs. For the diet treatment period (d 87 to 120), IC pigs gained 0.10 kg/d more ($P < 0.0001$) than PC pigs while RAC-fed pigs gained 0.16 kg/d more ($P < 0.0001$) than control-fed pigs for the same period. For the entire study (d 0 to 120), IC pigs gained 0.02 kg/d more ($P < 0.0001$) than PC pigs; however, there were no differences ($P = 0.22$) between ADG of control-fed pigs and RAC-fed pigs when evaluated over the same time period.

There were no significant interactions between sex and diet for effects on ADFI in this study. For the first 65 d, PC pigs consumed 0.30 kg more ($P < 0.01$) feed per day than IC pigs; however, there were no differences ($P = 0.16$) between ADFI of PC pigs and IC pigs from

second Improvest dose to start of diet treatment (d 65 to 87). For the diet treatment period (d 87 to 120), IC pigs consumed 0.35 kg more ($P < 0.0001$) feed per day than PC pigs; however, IC pigs consumed 0.13 kg less ($P < 0.0001$) feed per day than PC pigs over the entire study period (d 0 to 120). There were no differences ($P \geq 0.40$) between ADFI of control-fed pigs and RAC-fed pigs over the diet treatment period (d 87 to 120) as well as over the entire study period (d 0 to 120).

For the first 65 d, IC pigs had a 0.044 greater ($P < 0.0001$) G:F than PC pigs. Similarly, IC pigs had a 0.035 greater ($P < 0.0001$) G:F than PC pigs from d 65 to 87. There was an interaction ($P = 0.02$) between sex and diet for effects on G:F during the diet treatment period (d 87 to 120). Feeding RAC increased ($P < 0.0001$) G:F for both PC and IC pigs, the magnitude of response was numerically, but not significantly, greater for PC pigs than IC pigs. Over the entire study period (d 0 to 120), IC pigs had a 0.025 greater ($P < 0.0001$) G:F than PC pigs while there were no differences ($P = 0.28$) between G:F of control-fed pigs and RAC-fed pigs over the same period.

Carcass Characteristics

There were no significant interactions between sex and diet for effects on slaughter weights, carcass weights, carcass fat depths, and carcass loin depths in this study. Immunological castrates were 2.48 kg heavier ($P < 0.0001$) than PC pigs and RAC-fed pigs were 2.88 kg heavier ($P < 0.0001$) than control-fed pigs at slaughter (Table 3.4). For market group effects, market group 3 pigs were 1.84 kg heavier ($P < 0.01$) than market group 1 pigs which were 1.36 kg heavier ($P = 0.02$) than market group 2 pigs at slaughter. There were no differences ($P = 0.10$) between weights of PC and IC carcasses; however, RAC-fed carcasses were 2.32 kg heavier ($P < 0.0001$) than control-fed carcasses. Carcasses from market group 3 pigs were 3.12 kg and 3.17 kg heavier ($P < 0.0001$) than carcasses from market group 2 and 1

pigs, respectively; however, there were no differences ($P = 0.90$) between carcass weights of market groups 2 and 1 pigs. The similarities in carcass weights of PC and IC pigs is due to PC pigs having a 1.78 percentage unit greater ($P < 0.0001$) dressing yield than IC pigs. There was no interaction ($P = 0.25$) between sex and market group for effects on dressing yield; however, dressing yields of immunological castrates increased ($P < 0.001$) as time after second dose increased where dressing yields were 72.09%, 72.82%, and 73.58% for IC pigs from market groups 1, 2, and 3, respectively. Additionally, there were no differences ($P = 0.21$) between dressing yields of control-fed and RAC-fed pigs.

There was an interaction ($P < 0.01$) between sex and market group for effects on carcass backfat depth. For market group 1 pigs, PC carcasses had 2.29 mm more ($P < 0.0001$) backfat than IC carcasses. Similarly, PC carcasses had 1.48 mm more ($P < 0.01$) backfat than IC carcasses for market group 2 pigs; however, there were no differences ($P = 0.91$) between PC and IC carcass fat depths from market group 3 pigs. There were no differences ($P = 0.10$) between fat depths of control-fed and RAC-fed carcasses. Physical castrate carcasses had loins that were1.65 mm deeper ($P < 0.0001$) than those of IC carcasses. Additionally, RAC-fed carcasses had loins that were 2.19 mm deeper ($P < 0.0001$) than those of control-fed carcasses. Carcasses from market group 2 pigs tended ($P = 0.08$) to have loins that were 1.03 mm deeper than those from market 3 pigs which were 1.56 mm deeper ($P < 0.01$) than loins from market group 1 pigs.

There was an interaction ($P = 0.04$) between sex, diet, and market group on Fat-O-Meater estimated lean (Figure 3.1). In market group 1, feeding RAC increased ($P = 0.03$) estimated leanness of IC carcasses but not PC carcasses ($P = 0.79$), while in group 2, RAC increased ($P =$

0.02) estimated leanness of PC carcasses but not IC carcasses ($P = 0.41$). In market group 3, however, feeding RAC increased ($P \leq 0.01$) leanness of both PC and IC carcasses.

DISCUSSION

The lack of interactions between immunological castration and RAC feeding in the present study fully supports the idea that these technologies are additive in terms of improving growth performance and carcass characteristics. During the last 33 d of feeding, RAC-fed IC pigs grew 29% faster and were 17% more feed efficient than control-fed PC pigs. Furthermore, RAC-fed IC carcasses were 2% heavier, had 7% less fat, and were estimated to be 0.59 percentage units leaner than control-fed PC carcasses. These findings are comparable to others who have reported similar additive effects of immunological castration and RAC feeding on growth performance and carcass characteristics (Moore et al., 2009; Rikard-Bell et al., 2009). It must be noted, however, that pigs used in the present study were approximately 20-30 kg heavier at slaughter than those used in previous studies (Moore et al., 2009; Rikard-Bell et al., 2009) and therefore more in line with contemporary US slaughter weights.

Similar to the findings in the present study, supplementation of pigs with 5 mg/kg RAC generally results in increased BW, greater ADG, and improved feed efficiencies (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004, 2005; See et al., 2005; Patience et al., 2009; Hinson et al., 2012) while having no effects on ADFI (Apple et al., 2007; Patience et al., 2009). Additionally, carcasses from RAC-fed pigs are consistently heavier and have greater muscling than there control-fed counterparts (Apple et al., 2007; Carr et al., 2009; Kutzler et al., 2011). During protein turnover, growth efficiency is decreased due to energy lost during protein remodeling (Pringle et al., 1993); however, β-agonist administration, such as

RAC, improves efficiency by inhibiting energy storage and protein degradation while stimulating energy mobilization and protein synthesis (Lynch et al., 2008).

Many of the reports on immunological castration focus on the time following the second dose of the immunological compound and consistently demonstrate that IC pigs have greater ADG, are more feed efficient, and have greater feed intakes than PC pigs (Dunshea et al., 2001; Pauley et al., 2009; Morales et al., 2011); however, economic effects of immunological castration are greater when evaluated over the entire production period. Over the entire 120-d production period in the present study, IC pigs grew 3% faster and were 7% more feed efficient while consuming 5% less feed than PC pigs. It is important to understand that these findings are not the results of immunological castration, but are the results of delaying castration until later in production. This delaying of castration allows producers to take advantage of the improved efficiencies of boars (Xue et al., 1997) while reducing the presence of boar taint compounds (Dunshea et al., 2001; Bonneau et al., 2000). Production profitability when using immunological castration is directly related to time of castration where profitability is limited when castration is performed earlier in production (Pauly et al., 2009).

In addition to effects on growth performance, IC pigs are consistently heavier at slaughter, have decreased dressing percentages, similar carcass weights, less carcass fat, and improved carcass leanness when compared to PC pigs (Bonneau et al., 1994; Dunshea et al., 2001; Pauly et al., 2009; Boler et al., 2012). The effects of immunological castration on dressing percentages are often attributed to the presence and removal of testicles and associated scrotal skin (Boler et al., 2012) and increased organ merit in IC than PC pigs (Pauly et al., 2009). Despite these differences in dressing percentages, IC carcasses consistently have cutability is

consistently increased due to increases in leanness and larger shoulders and hams commonly associated with boars (Richmond and Berg, 1982).

In conclusion, feeding RAC at 5 mg/kg improves growth performance and carcass characteristics of both physical castrates and immunological castrates. Additionally, immunological castration improved overall growth performance, slaughter weight, and carcass leanness. The use of these technologies are additive to each other and result in limited interactions. Therefore, RAC-fed immunological castrates are superior to control-fed physical castrates in terms of average daily gain, overall feed intake, and feed efficiency. Furthermore, feeding RAC to immunological castrates improves overall carcass value due to the reduced carcass fatness associated with immunological castration and increased muscling and carcass weights associated with feeding RAC.

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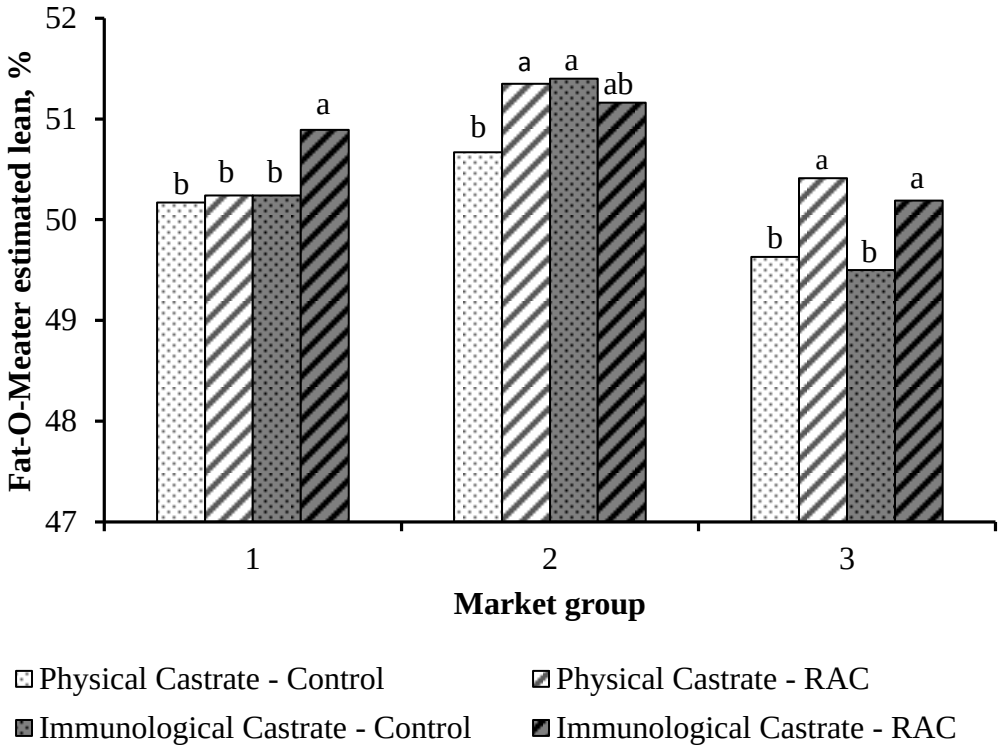
FIGURES

Figure 3.1. Effects of feeding ractopamine-HCl (RAC) to physical castrates and immunological castrates on Fat-O-Meater estimated lean yield. Market group: 1= fed RAC treatment for 12 d prior to harvest (4.5 wk post-second injection); 2 = fed RAC treatment for 19 d prior to harvest (5.5 wk post-second injection); 3 = fed RAC treatment for 33 d prior to harvest (7.5 wk post-second injection). a,b Means within market group effect lacking common superscripts differ ($P < 0.05$).



TABLES

Table 3.1. Composition of growing phase diets fed to physical castrates (PC) and immunological castrates (IC) on an as-fed basis.[1]

	Phase 1 (23 - 45 kg)		Phase 2 (45 - 68 kg)		Phase 3 (68 - 91 kg)		Phase 4 (91 - 109 kg)	
	PC	IC	PC	IC	PC	IC	PC	IC
Analyzed composition								
NRC ME (kcal/kg)	3369	3371	3391	3391	3395	3395	3395	3395
CP, %	17.44	19.82	15.22	16.71	13.73	15.42	12.69	14.70
Total lysine, %	1.16	1.33	0.95	1.05	0.84	0.95	0.74	0.84
SID lysine, %	1.05	1.20	0.85	0.95	0.75	0.85	0.65	0.75
Available P, %	0.35	0.35	0.30	0.30	0.25	0.25	0.25	0.25
Ca, %	0.65	0.65	0.55	0.55	0.50	0.50	0.50	0.50
SID Met+Cys:Lys	58	58	58	58	58	58	63	59
SID Thr:Lys	62	62	65	65	66	66	65	65
SID Trp:Lys	16	17	17	17	16	17	17	17
SID Ile:Lys	59	60	62	62	62	63	65	65
SID Val:Lys	67	67	72	72	74	73	79	77

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

Table 3.2. Ingredients and composition of control and ractopamine (RAC) finishing (109 kg – market) diets fed to physical castrates and immunological castrates on an as-fed basis.[1]

	Physical Castrate		Immunological Castrate	
	Control	RAC	Control	RAC
Ingredient, %				
Corn	85.61	73.84	85.61	73.84
Soybean meal (48% CP)	11.25	23.00	11.25	23.00
Choice white grease	1.00	1.00	1.00	1.00
Monocalcium phosphate	0.13	0.13	0.13	0.13
Limestone	1.15	1.05	1.15	1.05
Salt	0.50	0.50	0.50	0.50
L-Lysine	0.22	0.22	0.22	0.22
Alimet[2]	-	0.03	-	0.03
L-Threonine	0.06	0.10	0.06	0.10
Vitamin Premix[3]	0.03	0.03	0.03	0.03
Mineral Premix[4]	0.04	0.04	0.04	0.04
OptiPhos-2000[5]	0.01	0.01	0.01	0.01
Paylean 9[6]	-	0.03	-	0.03
Analyzed composition				
NRC ME (kcal/kg)	3395	3395	3395	3395
CP, %	12.70	17.36	12.70	17.36
Total Lys, %	0.74	1.06	0.74	1.06
SID Lys, %	0.65	0.95	0.65	0.95
Available P, %	0.25	0.25	0.25	0.25
Ca, %	0.50	0.50	0.50	0.50
SID Met+Cys:Lys	63	58	63	58
SID Thr:Lys	68	68	68	68
SID Trp:Lys	17	18	17	18
SID Ile:Lys	65	65	65	65
SID Val:Lys	79	74	79	74

[1] Male pigs immunologically castrated by giving 2 doses of Improvest (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.
[2]Alimet, Novus, St. Charles, MO
[3]Provided per kg of final diet: vitamin A: 11,000 IU; vitamin D3: 1,760 IU; vitamin E: 44 IU; riboflavin: 8.25 mg; menadione: 4.4 mg; vitamin B12: 0.04 mg; D-pantothenic acid: 27.5 mg; and niacin: 49.50 mg
[4]Provided per kg of final diet: Iron: 165 mg; Zinc: 165 mg; Manganese: 49.5 mg; Copper: 165 mg; Iodine: 0.35 mg; Selenium: 0.30 mg
[5]OptiPhos 2000, Phytex LLC, subsidiary of JBS United Inc., Sheridan, IN; added where final concentration of phytase was 0.55 g/kg of diet
[6]Paylean 9, Elanco Animal Health, Greenfield, IN; added where final concentration of RAC was 5 mg/kg of diet

Table 3.3. Effects of physical castrate (PC) and immunological castrate (IC) pigs fed either a control diet or a diet containing 5 mg/kg ractopamine hydrochloride (RAC) in a commercial setting on growth performance.[1,2]

	PC		IC			*P*-values		
Item	Control	RAC	Control	RAC	SEM	Sex	Diet	Sex × Diet
BW, kg								
d 0	27.30	-	27.29	-	0.45	0.96	-	-
d 65	93.31[a]	-	92.26[b]	-	1.33	0.02	-	-
d 87	113.73	113.84	114.04	114.39	0.99	0.52	0.65	0.71
d 120	135.81[c]	139.81[b]	138.22[b]	142.92[a]	1.28	< 0.01	< 0.0001	0.66
ADG, kg/d								
d 0 to 65	1.01[a]	-	1.00[b]	-	0.01	< 0.01	-	-
d 65 to 87	0.89[b]	-	0.96[a]	-	0.06	< 0.0001	-	-
d 87 to 120	0.87[d]	1.03[b]	0.97[c]	1.12[a]	0.02	< 0.0001	< 0.0001	0.55
d 0 to 120	0.96[c]	0.99[bc]	0.99[ab]	1.01[a]	0.01	< 0.0001	0.22	0.81
ADFI, kg/d								
d 0 to 65	2.58[a]	-	2.28[b]	-	0.06	< 0.0001	-	-
d 65 to 87	3.07	-	2.94	-	0.12	0.16	-	-
d 87 to 120	3.36[b]	3.32[b]	3.69[a]	3.69[a]	0.03	< 0.0001	0.42	0.61
d 0 to 120	2.85[a]	2.83[a]	2.70[b]	2.72[b]	0.01	< 0.0001	0.90	0.05
G:F, kg:kg								
d 0 to 65	0.393[b]	-	0.437[a]	-	0.004	< 0.0001	-	-
d 65 to 87	0.290[b]	-	0.325[a]	-	0.007	< 0.0001	-	-
d 87 to 120	0.258[b]	0.311[a]	0.263[b]	0.303[a]	0.005	0.64	< 0.0001	0.02
d 0 to 120	0.338[c]	0.349[bc]	0.366[ab]	0.371[a]	0.004	< 0.0001	0.28	0.22

[a, b, c, d] Means within row lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk (d 65) of age.

[2] Study time periods: d 0 = allotment to pens (start of study); d 65 = second injection with Improvest; d 87 = start of diet treatment; d 120 = completion of study.

Table 3.4. Effects of physical castrate (PC) and immunological castrate (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine hydrochloride (RAC) and main effects of market group on carcass characteristics.[1]

	PC		IC			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Slaughter wt, kg	134.64^{c}	137.47^{b}	137.07^{b}	139.99^{a}	0.65	137.13^{b}	135.78^{c}	138.97^{a}	0.60	S, D, M
Carcass wt, kg	100.38^{b}	102.64^{a}	99.71^{b}	102.09^{a}	0.71	100.18^{b}	100.13^{b}	103.30^{a}	0.69	D, M
Dressing yield, %	74.55^{a}	74.66^{a}	72.75^{b}	72.91^{b}	0.23	73.06^{c}	73.75^{b}	74.35^{a}	0.22	S, M
Fat-O-Meater										
Fat depth, mm	25.94^{a}	25.37^{a}	24.53^{b}	24.23^{b}	0.45	24.71^{b}	23.74^{c}	26.60^{a}	0.43	S, M, SM
Loin depth, mm	60.02^{b}	62.37^{a}	58.53^{c}	60.56^{b}	0.61	58.98^{b}	61.58^{a}	60.55^{a}	0.56	S, D, M
Estimated lean, %	50.16^{c}	50.67^{ab}	50.38^{bc}	50.75^{a}	0.12	50.39^{b}	51.15^{a}	49.93^{c}	0.11	D, M, SDM

$^{a, b, c}$ Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= fed RAC treatment for 12 d prior to harvest (4.5 wk post-second injection); 2 = fed RAC treatment for 19 d prior to harvest (5.5 wk post-second injection); 3 = fed RAC treatment for 33 d prior to harvest (7.5 wk post-second injection).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Chapter 4

EFFECTS OF FEEDING RACTOPAMINE HYDROCHLORIDE (PAYLEAN®) TO PHYSICALLY AND IMMUNOLOGICALLY CASTRATED (IMPROVEST®) PIGS IN A COMMERCIAL SETTING ON CARCASS CUTTING YIELDS AND FRESH MEAT QUALITY

ABSTRACT

Thirty-two pens with 22 pigs per pen were used to evaluate effects of feeding ractopamine (RAC; 5 mg/kg) to physically castrated (PC) and immunologically castrated (IC) pigs on carcass characteristics, cutting yields, and pork quality. Male pigs were randomly assigned to sex treatments at birth and fed the same nursery diets prior to allotment in a grow-finish barn. Pigs in the PC treatment were surgically castrated at 5 d of age and pigs in the IC treatment were administered Improvest at 11 and 18 wk of age. Diet treatments (control or RAC) were initiated on d 87 of study and final treatment arrangement was a 2 x 2 factorial of sex and diet. Data were analyzed using PROC MIXED in SAS with fixed effects of sex, diet, market group, and their interaction; carcass (N=285) was experimental unit. Carcasses from RAC-fed pigs were heavier (P<0.01) and had deeper (P=0.02) loins than control-fed carcasses. Carcasses from IC pigs were similar (P=0.22) in weight but had less (P<0.01) fat and shallower (P=0.02) loins when compared to PC carcasses. There were differences (P<0.05) among market groups for carcass weights, fat depths, loin depths, and estimated carcass leanness. For cutting yields, RAC-fed carcasses had greater (P≤0.03) bone-in lean and total carcass cutting yields than control-fed carcasses while there were no differences (P>0.05) between control-fed and RAC-fed carcasses when evaluating LM color, marbling, firmness, pH, drip loss, and tenderness. Carcasses from IC

pigs had greater (P<0.05) boneless lean yields, bone-in lean yields, and total carcass cutting yields than IC carcasses while having minimal effects (P<0.05) on LM marbling, firmness, composition, and tenderness. There was an interaction (P=0.03) between sex and diet for LM composition where control-fed PC loins had more (P<0.01*)* lipid than all other treatment combinations. Market group had effects (P<0.05) on carcass cutting yields, LM color, marbling and firmness scores, pH, purge loss, composition, and tenderness. The results from this study indicate that RAC and immunological castration are additive in terms of improving carcass cutting yields while having minimal effects on pork quality.

INTRODUCTION

Ractopamine hydrochloride (RAC), commercially available as Paylean® (Elanco Animal Health, Greenfield, IN), is a β-adrenergic agonist for use in finishing swine diets. Feeding RAC increases carcass weights and muscling (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004; See et al., 2005; Apple et al., 2007; Carr et al., 2009; Kutzler et al., 2011) while increasing carcass cutting yields (Bohrer et al., 2013). Despite the effects reported on carcass characteristics and cutting yields, studies have demonstrated that feeding RAC has little impact on fresh meat quality including LM color scores (Rincker et al., 2005), marbling scores (Carr et al., 2009), firmness scores (Stites et al., 1994), and pH (Leick et al., 2010).

Improvest® (Zoetis, Kalamazoo, MI) is an immunological product that was developed for the control of boar taint in intact male pigs. Immunologically castrated (IC) pigs consistently have greater ADG and improved feed efficiency (Pauly et al., 2009; Morales et al., 2011) when compared to physical castrated (PC) pigs following second Improvest dose. Despite having decreased dressing percentages (Morales et al., 2011; Boler et al., 2012), carcasses from IC pigs are consistently leaner than PC pigs due to having less carcass fat (Dunshea et al., 2001; Jaros et

al., 2005; Pauly et al., 2009; Morales et al., 2011) which ultimately results in increased carcass cutting yields (Boler et al., 2012).

There is limited data documenting the effects of feeding RAC to PC and IC pigs simultaneously. Studies have shown that feeding RAC and immunological castration are additive. Feeding RAC to IC pigs increases ADG and improves feed efficiency (Rikard-Bell et al., 2009) while improving carcass characteristics (Moore et al., 2009). Therefore, the objective of this study was to evaluate the effects of feeding RAC to PC and IC pigs in a commercial setting on carcass cutting yields and fresh pork quality.

MATERIALS AND METHODS

All animals used during for this study were cared for in accordance with University of Missouri Animal Care and Use Committee guidelines. No approval from the University of Illinois Institutional Animal Care and Use Committee was obtained for this study because carcasses were obtained from a federally inspected slaughter facility.

Slaughter

Pigs used in this portion of the study were a subset of pigs used to evaluate feeding RAC to physically castrated (PC) and immunologically castrated (IC) pigs in a commercial setting as described in Chapter 3. To follow commercial production practices, pigs were selected for slaughter based on ending live weight; the heaviest pigs in each pen were selected based on individual live weights and identified. Pigs were marketed at 12 d (4.5 wk post-second Improvest dose), 19 d (5.5 wk post-second Improvest dose), and 33 d (7.5 wk post-second Improvest dose) following the start of final diet treatments. For market group 1 (12 d on diet treatment), pens were standardized to 17 pigs per pen. For market group 2 (19 d on diet treatment), pens were standardized to 9 pigs per pen. All remaining pigs were marketed in group

3 (33 d on diet treatment). After selection, pigs were tattooed on shoulders and hams for identification in the processing facility. Additionally, the three pigs closest to the pen mean of pigs being marketed were identified and tattooed on the belly and loin as well for evaluation of carcass cutting yields and meat quality evaluations. Pigs were loaded onto commercial trucks and transported (263 km) to a federally inspected abattoir where they were held overnight with access to water. Pigs were slaughtered and carcasses chilled according to industry standards. Carcass data including carcass weight, Fat-O-Meater fat depth, LM depth, and estimated percent lean were collected at harvest by plant personnel. All data presented is that of the pigs selected for carcass cutting yields and meat quality evaluations.

Carcass Fabrication

Due to constraints in the commercial plant, we were unable to collect all carcasses identified for carcass cutting yields. In total, 285 carcasses were collected and used for carcass cutting yields over the course of this study. Of the 285 carcasses, 71 were from control-fed PC pigs, 72 from RAC-fed PC pigs, 72 from control-fed IC pigs, and 70 from RAC-fed IC pigs.

Following chilling, skin-on primals including whole shoulders (jowl, foot, and neck bones attached), loins, hams (foot attached), and bellies (spareribs left on) were collected from left sides of carcasses. Primals were bulk packaged and transported to the University of Illinois Meat Science Lab for carcass fabrication and further data collection. Carcasses were fabricated according to guidelines of the Institutional Meat Purchasing Specifications (**IMPS**) as described by the North American Meat Processors Association (NAMP, 2007). Weights were collected on each primal piece prior to fabrication and subprimal cuts following fabrication. Carcass cutout data were also expressed as a percentage of HCW by multiplying the weight of the cut by two and dividing by the HCW.

Jowls, feet, and neckbones were removed from shoulders to yield IMPS#403 pork shoulders and classified as whole shoulders. Shoulders were skinned and fat removed to yield IMPS#404 skinned shoulders. Boston butts were separated from picnics to yield IMPS#406 bone-in Boston butts and IMPS#405 bone-in picnic shoulders. Bones were removed to yield IMPS#406A boneless Boston butts and IMPS#405A boneless picnic shoulders. Boneless picnic shoulders were further fabricated to yield IMPS#405B cushions (*triceps brachii*).

Skin-on bone-in loins were skinned and fat trimmed to yield IMPS#410 bone-in loins. Trimmed loins were further fabricated to yield IMPS#414 Canadian backs, IMPS#415A tenderloins (side muscle off), IMPS#410A purchaser specified option 1 boneless sirloins, and IMPS#422 backribs. Identities of Canadian back loins were retained for later evaluation of quality attributes.

Feet were removed from hams to produce IMPS#401 hams and designated as whole hams. Whole hams were skinned and excess fat removed for determination of trimmed ham weight. Trimmed hams were fabricated to yield IMPS#402F inside hams, IMPS#402E outsides, IMPS#402H knuckles, and light butts. Whole spareribin bellies were fabricated to yield IMPS#408 bellies and IMPS#416 spareribs. Teat lines were removed and flank ends squared to produce trimmed and squared bellies.

Cutting Yields

Boneless lean cutting yields were calculated using the following equation: Boneless lean cutting yield = [2 × (boneless Boston butt + boneless picnic + Canadian back + tenderloin + sirloin + light butt + knuckle + inside ham + outside ham) / HCW] × 100. Bone-in lean cutting yields were calculated using the following equation: Bone-in lean yield = [2 × (trimmed Boston butt + trimmed picnic + trimmed loin + trimmed ham) / HCW] × 100. Carcass cutting yields

were calculated using the following equation: Carcass cutting yield = [2 × (components from bone-in lean yield + squared belly) / HCW] × 100.

Pork Quality

Pork quality evaluations including pH, objective color, subjective color, marbling, firmness, drip loss, and purge loss were conducted by trained University of Illinois Meat Science Lab personnel. Boneless Canadian back loins (IMPS#414) were cut in the area of the 10th rib to expose the loin face. Ultimate pH was measured using a pH star probe equipped with a glass electrode (SFK Technologies Inc., Cedar Rapids, IA; calibrated at 2 points, pH 4 and 7). Objective CIE *L**, *a**, and *b** (CIE, 1978) were collected with a Minolta CR-400 Chroma meter (Minolta Camera Company, Osaka, Japan) using a D65 illuminant, a 0° observer, an 8 mm aperture, and a Minolta DP-400 Data Processor calibrated to a white tile of known values. Subjective color and marbling scores (NPPC, 1999) and firmness scores (NPPC, 1991) were conducted by a single individual according to standards of the National Pork Producers Council on both the underside of the whole loin and the loin face. Following loin face quality data collection, loins were flipped so that the loin portion adjacent to the ribs was facing up. Subjective color, marbling, and firmness scoring was conducted on the entire loin and deemed ventral side loin color, marbling, and firmness.

Following pork quality measurements, a chop (2.54 cm) was obtained just posterior to the cut face for moisture and lipid content determination. Chops were removed of all external fat, homogenized in a food processor (Cuisinart model CUI DFP-7BC, Cuisinart, East Windsor, NJ), and duplicate 10 g samples of tissue were oven dried at 110° C for approximately 24 h. Dried samples were washed multiple times in an mixture of warm chloroform:methanol (4:1) as described by Novakofski et al. (1989) to determine total extractable lipid. Drip loss was

determined by obtaining and suspending a 1.27 cm-thick chop from a fish hook inside a Whirl-Pak bag for approximately 24 h at 2˚C. Weights were obtained just prior to and immediately following chilling. Drip loss was reported as the amount of moisture lost as a percentage of the initial weight. Two chops (2.54 cm thick) were removed from the remaining loin portion, vacuum packaged, assigned to aging times (either 14 or 21 d), stored (2˚C), and then frozen (-33°C) for determination of Warner-Bratzler shear force. Remaining loin sections were weighed, vacuum packaged in shrinkable cryovac bags, placed in a water bath (88˚C) for 3 s, and stored at 4˚C for 14 d to determine purge loss. Following storage, loins were removed from packages, placed on wire racks for 20 min, and weighed. Purge loss was reported as the amount of moisture lost as a percentage of initial weight.

Warner-Bratzler Shear Force

Chops for Warner-Bratzler shear force determination were removed from frozen storage and allowed to thaw (2˚C) for 24 h. Chops were trimmed of excess fat and cooked on preheated broilers (model 455N Open Hearth Broiler, Farberware, Bronx, NY). Chops were cooked to an internal temperature of 35˚C on one side, flipped, and cooked to a final internal temperature of 70˚C. Internal temperature was monitored by copper constantan thermocouples (Type T, Omega Engineering, Stamford, CT) placed in the geometric center of each chop and connected to a digital scanning thermometer (model 92000-00, Barnant Co., Barington, IL). Chops were allowed to cool to 25˚C and 6 cores (1.27 cm diameter) were removed parallel to the orientation of the muscle fibers. Each core was sheared perpendicular to the fiber orientation using a Texture Analyzer TA.HD Plus (Texture Texhnologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) equipped with a Warner-Bratzler shear head with a blade speed of 3.3 mm/sec and a load cell capacity of 100 kg. Shear force was reported as the average of the

6 cores. Cook loss was determined by weighing chops just prior to and immediately following cooking. Cook loss is reported as weight lost during cooking as a percentage of pre-cooked weight.

Statistical Analysis

Data were analyzed using the MIXED procedure in SAS (SAS Inst., Cary, NC) and carcass served as the experimental unit for all analyses. Data were analyzed as a split-plot design with sex and diet combination serving as the whole plot and market group serving as the split plot. Any three-way interactions between sex, diet, and market group were sliced by market group to further distinguish treatment effects. Replication served as a random variable in all models. Cook loss and Warner-Bratzler shear force of chops were analyzed as repeated measures with identity serving as subject, age repeated, and with an unstructured covariate structure based on Akaike's information criteria. Single degree of freedom contrast statements were used to make pair-wise comparisons between treatment groups for any significant interactions. Least squares means and coefficients for single degree of freedom contrast statements were generated using LSMEANS. Normality of residuals was checked using the CAPABILITY procedure and outliers were left in the data set unless deemed physiologically impossible. Homogeneity of variances were tested using the Levene's test or the Brown and Forsythe's test in the case of non-normal data using the GLM procedure in SAS. Effects were deemed significant at $P < 0.05$.

RESULTS

Carcass Characteristics

There was an interaction ($P = 0.01$) between sex and market group on carcass fat where IC carcasses had 2.56 mm and 1.51 mm less ($P < 0.01$) fat than PC carcasses at market group 1

(4.5 wk post-second Improvest dose) and market group 2 (5.5 wk post-second Improvest dose), respectively; however, IC and PC carcasses had similar ($P = 0.89$) fat depths for market group 3 (7.5-wk post-second Improvest dose; Table 4.1). Loins from PC carcasses were 1.36 mm deeper ($P = 0.02$) than those from IC carcasses. Additionally, there were no differences ($P = 0.68$) between weights of PC and IC carcasses as well as no differences ($P = 0.14$) between estimated leanness of PC and IC carcasses. Carcasses from RAC-fed pigs were 1.27 kg (1.3%; $P < 0.01$) heavier than those from control-fed pigs. Additionally, RAC-fed carcasses had loins that were 1.26 mm deeper ($P = 0.03$) than those from control-fed carcasses while there were no differences ($P = 0.27$) between fat depths of control-fed and RAC-fed carcasses. Carcasses from RAC-fed pigs tended ($P = 0.07$) estimated to be 0.29 percentage units leaner than control-fed carcasses. Market group 3 carcasses were 3.14 kg and 2.90 kg heavier ($P < 0.0001$) than market group 1 and market group 2 carcasses, respectively; however, market group 1 and 2 carcasses were similar ($P = 0.22$) in weight. Market group 2 carcasses had 2.72 mm deeper ($P < 0.01$) loins than market group 1 carcasses which tended ($P = 0.08$) to be 1.29 mm deeper than market group 1 carcasses. Market group 2 carcasses were estimated to be 1.03 percentage units leaner ($P < 0.0001$) than market group 1 carcasses which were estimated to be 0.70 percentage units leaner ($P < 0.001$) than market group 3 carcasses.

Carcass Cutting Yields

There was an interaction ($P < 0.04$) between sex, diet, and market group for bone-in and boneless Boston butts when represented as a percentage of HCW (Table 4.2). In market group2, feeding RAC increased ($P \leq 0.02$) bone-in and boneless Boston butt values in PC carcasses while having no effects ($P \geq 0.36$) in IC carcasses. In market groups 1 and 3, feeding RAC did not have an effect ($P > 0.05$) on bone-in and boneless Boston butts expressed as a percentage of HCW in

either sex. Bone-in picnics, boneless picnics, and cushions from IC carcasses were heavier ($P < 0.01$) than those from PC carcasses. Whole shoulders, bone-in picnics, boneless picnics, and cushions from IC carcasses made up a greater ($P < 0.03$) percentage of HCW than those from PC carcasses. Whole shoulders and boneless picnics from RAC-fed carcasses were heavier ($P < 0.05$) than those of control-fed carcasses. Market group had an effect ($P < 0.05$) on whole shoulder, bone-in Boston butt, boneless Boston butt, cushion, and jowl weights. Market group had an effect ($P \leq 0.03$) on whole shoulders, bone-in picnics, cushions, and jowls expressed as a percentage of HCW.

There were no significant interactions between sex, diet, and market group on any loin cutting yields in this study (Table 4.3). There were interactions ($P \leq 0.04$) between sex and market group on tenderloin and sirloin weights as well as tenderloins and sirloins expressed as a percentage of HCW. Tenderloins and sirloins from IC carcasses were heavier ($P \leq 0.04$) and represented a greater ($P \leq 0.02$) percentage of HCW than those from PC carcasses in market group 2; however, there were no differences ($P \geq 0.22$) between PC and IC carcasses when evaluating tenderloin and sirloins in market groups 1 and 3. Whole loins from PC carcasses made up a greater ($P = 0.03$) percentage of HCW than those from IC carcasses; however, trimmed loins and Canadian backs from IC carcasses made up a greater ($P < 0.05$) percentage of HCW than those from PC carcasses. Whole loins, trimmed loins, and backribs from PC carcasses were similar ($P \geq 0.15$) in weight to those from IC carcasses. Additionally, there were no differences ($P = 0.89$) between backribs from PC carcasses and those from IC carcasses when expressed as a percentage of HCW. There was an interaction ($P = 0.03$) between diet and market group for effects on Canadian back weights. In market groups 1 and 2, Canadian backs from RAC-fed carcasses were heavier ($P < 0.03$) than those from control-fed carcasses; however,

there were no differences ($P = 0.56$) between control-fed and RAC-fed Canadian back weights in market group 3. Whole loins, trimmed loins tenderloins, and sirloins from RAC-fed carcasses were heavier ($P < 0.04$) than those from control-fed carcasses. Trimmed loins, Canadian backs, tenderloins, and sirloins from RAC-fed carcasses represented a greater ($P \leq 0.03$) percentage of HCW than loin components from control-fed carcasses. Backribs from market group 3 carcasses were heavier ($P < 0.01$) than those from market group 1 carcasses which were heavier ($P < 0.01$) than those from market group 2 carcasses. Additionally, market group effected ($P < 0.01$) trimmed loins, Canadian backs, and backribs when expressed as a percentage of HCW.

There was an interaction ($P = 0.04$) between sex and market group on trimmed ham weights (Table 4.4). Trimmed hams from IC carcasses were heavier ($P < 0.01$) than those from PC carcasses in market group 2; however, there were no differences ($P \geq 0.16$) between trimmed ham weights of PC and IC carcasses in market groups 1 and 3. Additionally, there was an interaction ($P = 0.03$) between sex and market group on trimmed hams when expressed as a percentage of HCW. Hams from IC carcasses represented a greater ($P < 0.01$) percentage of HCW than those from PC carcasses in market groups 1 and 2; however, there were no differences between PC and IC hams when expressed as a percentage of HCW in market group 3. There were interactions ($P < 0.03$) between diet and market group for trimmed ham and light butt weights where trimmed hams and light butts from RAC-fed carcasses were heavier ($P \leq 0.02$) than those from control-fed carcasses in market group 2; however, there were no differences ($P \geq 0.18$) between control-fed and RAC-fed carcasses when evaluating trimmed ham and light butt weights in market groups 1 and 3. Similarly, there was also an interaction ($P = 0.03$) between diet and market group on light butts when expressed as a percentage of HCW. In market group 2, light butts from RAC-fed carcasses tended ($P = 0.09$) to represent a greater

percentage of HCW; however, there were no differences ($P \geq 0.12$) between control-fed and RAC-fed carcasses when evaluating light butts as a percentage of HCW in market groups 1 and 3. Inside hams from IC carcasses tended ($P = 0.07$) to be heavier than those from PC carcasses. Whole hams, inside hams, outside hams, knuckles, and light butts from IC carcasses represented a greater ($P < 0.05$) percentage of HCW than those from PC carcasses; however there were no differences ($P = 0.33$), between PC and IC carcasses when evaluating whole ham weights.

There were no differences ($P \geq 0.19$) between control-fed and RAC-fed carcasses when evaluating whole ham and inside ham weights. Additionally, there were no differences ($P \geq 0.17$) between whole hams, inside hams, outside hams, and knuckles from control-fed carcasses and those from RAC-fed carcasses when expressed as a percentage of HCW. Whole hams light butts from market group 1 and 2 carcasses represented a greater ($P < 0.0001$) percentage of HCW than those from market group 3 carcasses while there were no differences between market group 1 and 2 carcasses when evaluating whole hams and light butts expressed as a percentage of HCW. Additionally, trimmed hams from market group 1 carcasses tended ($P = 0.09$) to represent a greater percentage of HCW than those from market group 2 carcasses while trimmed hams from market group 2 carcasses represented a greater ($P < 0.0001$) percentage of HCW than those from market group 3 carcasses. Furthermore, outside hams from market group 1 carcasses tended ($P = 0.06$) to represent a greater percentage of HCW than those from market group 2 carcasses while outside hams from market group 2 carcasses represented a greater ($P < 0.01$) percentage of HCW than those from market group 3 carcasses. There were no effects of market group ($P \geq 0.49$) on whole ham and inside ham weights.

Whole bellies, natural fall bellies, and squared bellies from PC carcasses were heavier ($P \leq 0.02$) and made up a greater ($P \leq 0.02$) percentage of HCW than those from IC carcasses

whereas spareribs from IC carcasses were heavier ($P < 0.01$) and made up a greater ($P < 0.01$) percentage of HCW than those from PC carcasses (Table 4.5). Market group had an effect ($P < 0.0001$) on whole belly weights, natural fall belly weights, and squared belly weights. There were no differences ($P \geq 0.12$) between any belly components from control-fed carcasses and those from RAC-fed carcasses on a weight basis or when expressed as a percentage of HCW. Additionally, market group had an effect ($P < 0.0001$) on whole bellies, spareribs, natural fall bellies, and squared bellies when expressed as a percentage of HCW.

Overall, immunological castration and feeding RAC increased cutting yields in this study though there were differences among market groups (Table 4.6). Carcasses from IC pigs had 1.19 percentage units greater ($P < 0.001$) boneless lean yields, 1.64 percentage units greater ($P < 0.0001$) bone-in lean yields, and 1.32 percentage units greater ($P < 0.0001$) total carcass cutting yields than PC carcasses. Additionally, RAC-fed carcasses tended ($P = 0.06$) to have 0.70 percentage units greater boneless lean yields, 0.76 percentage units greater ($P = 0.03$), and 0.70 percentage units greater ($P = 0.01$) total carcass cutting yields than control-fed carcasses. Market group 1 carcasses had boneless lean yields that were 0.73 and 1.12 percentage units greater ($P \leq 0.02$) than market group 2 and market group 3 carcasses, respectively. There were no differences ($P = 0.19$) between boneless lean yields of market group 2 and market group 3 carcasses. For both bone-in lean yields and total carcass cutting yields, market group 1 carcasses had greater ($P \leq 0.01$) yields than market group 2 carcasses which had greater ($P < 0.01$) yields than market group 3 carcasses.

Pork Quality

There were no significant interactions between sex, diet, and market group for any fresh pork quality characteristics measured in this study (Table 4.7). There was an interaction ($P <$

0.01) between sex and market group for loin cut surface marbling scores. For market groups 1 and 2, PC loins had approximately 0.35 units more ($P < 0.01$) marbling than IC loins; however, there were no differences ($P = 0.17$) between marbling scores of PC and IC loins for market group 3. There was also an interaction ($P = 0.04$) between sex and market group for loin b* values. For market group 1, PC loins had greater ($P = 0.01$) values than IC loins; however, there were no differences ($P \geq 0.18$) between b* values of PC and IC loins in market groups 1 and 3. There was also an interaction ($P = 0.03$) between sex and market group on LM lipid content. Loins from PC carcasses had more ($P < 0.01$) lipid than those from IC carcasses in market groups 1 and 2; however, there were no differences ($P = 0.49$) between lipid content of PC and IC loins in market group 3. There were interactions ($P = 0.03$) between sex and diet on LM composition. Feeding RAC in the present study increased ($P < 0.01$) LM moisture and decreased ($P < 0.01$) LM fat in PC carcasses while having no effects ($P \geq 0.65$) in IC carcasses.

Loins from PC carcasses had 0.23 units more marbling ($P = 0.02$), were 0.20 units firmer ($P = 0.03$), and tended to be 0.12 units darker ($P = 0.07$) than IC loins when evaluated on the ventral side of loins. When evaluating pork quality on the cut surface of loins, loins from PC carcasses were 0.16 units firmer ($P = 0.03$) than IC loins; however, there were no differences ($P = 0.13$) between PC and IC loins when evaluating color scores. There were no differences ($P \geq 0.20$) between PC and IC loins when evaluating *L**, *a**, or pH. Loins from IC carcasses had greater ($P = 0.03$) drip losses than PC loins; however, IC loins only tended to have greater ($P = 0.07$) 14 d purge loss values. Only cooking and tenderness evaluations of chops aged for 14 d are presented due to there being no effect ($P \geq 0.12$) of aging time on any properties measured. There were no differences ($P = 0.49$) between cook losses of PC and IC chops; however, PC chops had WBS values that were 0.16 kg less ($P = 0.02$) than IC chops.

There were no differences ($P \geq 0.40$) between control-fed and RAC-fed loins when evaluating ventral side color and firmness; however, control-fed loins tended to have 0.13 units more ($P = 0.05$) marbling than RAC-fed loins. Loins from RAC-fed carcasses tended to be 0.10 units darker ($P = 0.07$) and have 0.18 units less ($P = 0.07$) marbling than control-fed loins; however, there were no differences ($P = 0.32$) between control-fed and RAC-fed loins when evaluating loin cut surface firmness. There were no differences ($P = 0.16$) between pH values of control-fed and RAC-fed loins. Similarly, there were no differences ($P \geq 0.11$) between control-fed and RAC-fed loins when evaluating L^* and a^* values; however, control-fed loins had b^* values that were 0.24 units greater ($P = 0.03$) than RAC-fed loins. There were no differences ($P \geq 0.44$) between control-fed loins and RAC-fed loins when evaluating drip loss, 14 d purge loss, chop cook loss, and chop WBS values.

For market group effects, market group 2 loins were darker ($P < 0.001$) than market group 3 loins which were darker ($P < 0.0001$) than market group 1 loins when evaluated on the ventral side. Additionally, market group 1 loins had more ($P = 0.02$) marbling than market group 3 loins when evaluated on the ventral side; however, there were no differences ($P \geq 0.38$) between market group 2 loins and any other market group. When evaluated on the cut surface, market group 2 loins were darker ($P = 0.04$) than market group 3 loins whereas there were no differences ($P \geq 0.17$) between color of market group 1 loins and those from any other market group. Market group 3 loins were firmer ($P \leq 0.01$) than both market group 1 and 2 loins whereas there were no differences ($P = 0.70$) between firmness of market group 1 and 2 loins.

Market group 3 loins had L^* values that were 1.51 units greater ($P < 0.001$) than market group 1 loins which were 1.42 units greater ($P < 0.001$) than market group 2 loins. Market group 3 loins had a^* values that were 0.75 units greater ($P < 0.0001$) than market group 1 loins which

were 0.35 units greater ($P < 0.05$) than market group 2 loins. Market group 3 loins had pH values that were 0.11 units greater ($P < 0.0001$) than market group 2 loins which had values that were 0.03 units greater ($P = 0.01$) than market group 3 loins. There were no market group effects ($P = 0.54$) on drip loss values; however, market group 1 loins had greater ($P < 0.01$) 14 d purge losses than market group 2 loins which had greater ($P < 0.0001$) losses than market group 3 loins. Market group 1 loins had more ($P < 0.0001$) moisture than market group 2 loins which had more ($P < 0.0001$) moisture than market group 3 loins. There were no effects ($P = 0.24$) of market group on cooking losses; however, market group 1 chops had greater ($P < 0.001$) WBS values than both market groups 2 and 3 chops whereas there were no differences ($P = 0.98$) between WBS values of market groups 2 and 3 chops.

DISCUSSION

The lack of interactions between immunological castration and RAC feeding in the present study fully supports the idea that these technologies are additive in terms of improving carcass characteristics and carcass cutting yields while having little to no impact on fresh pork quality. When evaluated across all three market groups, RAC-fed IC carcasses had 7% less fat, 1.9 percentage units greater boneless lean yields, 2.4 percentage units greater bone-in lean yields, and 2.0 percentage units greater total carcass cutting yields when compared to control-fed PC carcasses. These findings are comparable to results of others reporting similar results on carcass composition when evaluating feeding RAC to IC pigs. However, those carcasses were approximately 20 kg lighter than those in the present study (Moore et al., 2009; Rikard-Bell et al., 2009). In contrast, there have been no documented studies evaluating feeding RAC to PC and IC pigs simultaneously on carcass cutting yields and fresh meat quality.

The RAC-induced increase in carcass weights, muscling, and cutting yields found in the present study are comparable to those of others (Watkins et al., 1990; Stites et al., 1991; Herr et al., 2001; Armstrong et al., 2004; See et al., 2005; Apple et al., 2007; Fernández-Dueñas et al., 2008; Carr et al., 2009; Kutzler et al., 2011; Hinson et al., 2012ab; Bohrer et al., 2013). Feeding RAC in the present study increased boneless lean, bone-in lean, and carcass cutting yields by 0.70, 0.76, and 0.70 percentage units, respectively. Although these results of feeding RAC on cutting yields are less than those reported by Bohrer et al. (2013), the findings from the present study are within the 95% confidence intervals that Bohrer et al. (2013) reported. These changes in carcass composition and carcass cutting yields are expected due to the increased protein synthesis and lean accretion associated with RAC feeding (Adeola et al., 1992; Crome et al., 1996; Mersmann, 1998). Additionally, the finding that RAC had no impact on fresh pork quality are in agreement with others who have reported no differences between control-fed and RAC-fed loins in terms of pH (Stites et al., 1994; Rincker et al., 2005; Patience et al., 2009), marbling scores (Armstrong et al., 2004; Carr et al., 2009), firmness scores (Leick et al., 2010), drip loss (Rincker et al., 2005), and tenderness (Stites et al., 1994).

The findings in the present study where IC carcasses had less fat and increased cutting yields are comparable to those of others who reported similar results (Pauley et al., 2009; Boler et al., 2011; Boler et al., 2012). These changes in carcass composition are expected as IC pigs spend the majority of production as boars which characteristically have a greater lean:fat deposition when compared to PC pigs (Dunshea et al., 2001; Morales et al., 2011). This change in composition is also evident when evaluating LM lipid content where PC loins regularly have more lipid than IC loins (Boler et al., 2012). However, similar to the findings in the present study, Boler et al. (2012) reported that lipid content of IC loins increased as time after second

dose increased from 4 to 6 weeks. Although IC loins had significantly greater WBS values than PC loins in the present study, the differences in magnitude were only 0.16 kg. Others have reported no differences in LM tenderness after 14 d of aging (Batorek et al., 2012; Boler et al., 2012).

Although RAC and immunological castration had little impact on pork quality in the present study, it is interesting to note the variation in pork quality, especially tenderness, between market groups within a population. There is very limited data available evaluating the effects that market group has on pork quality; however, as pigs are marketed in a commercial setting, stocking density changes due to removal of heavier pigs. It is understood that growth (ADG) is directly related to stocking density (DeDecker et al., 2005). This change in ADG, and possibly compensatory growth, of pigs in later market groups could be the cause for the changes observed when evaluating cutting yields and tenderness seen in the present study.

In conclusion, both immunological castration and feeding ractopamine improved carcass characteristics and carcass cutting yields while having minimal to no effects on fresh pork quality. Furthermore, the two technologies are additive and only further improve carcass characteristics and cutting yields when used together. It is important to understand the variation between market groups in terms of pork quality, specifically tenderness, and further research is needed to fully investigate such variations.

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TABLES

Table 4.1. Effects of physical castrate and immunological castrate finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) and main effects of market group on carcass characteristics.[1]

	Physical Castrate		Immunological Castrate			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Carcass wt, kg	100.28^{ab}	101.20^{a}	99.42^{b}	101.05^{a}	0.52	99.37^{b}	99.60^{b}	102.50^{a}	0.45	D, M
Fat depth, mm	25.69^{a}	24.92^{a}	23.93^{b}	23.92^{b}	0.35	24.14^{b}	23.07^{c}	26.63^{a}	0.27	S, M, SM
Loin depth, mm	59.80^{ab}	61.38^{a}	58.75^{b}	59.70^{b}	0.57	58.15^{b}	62.15^{a}	59.43^{b}	0.44	S, D, M
Estimated lean, %	50.21^{b}	50.69^{a}	50.64^{ab}	50.74^{a}	0.16	50.46^{b}	51.49^{a}	49.76^{c}	0.13	M

$^{a, b, c}$ Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= fed diet treatment for 12 d prior to harvest (4.5 wk post-second Improvest dose); 2 = fed diet treatment for 19 d prior to harvest (5.5 wk post-second Improvest dose); 3 = fed diet treatment for 33 d prior to harvest (7.5 wk post-second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Table 4.2. Effects of physical castrate and immunological castrate finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of marketing group on left side carcass cut-out values from the shoulder.[1]

	Physical Castrate		Immunological Castrate			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Whole shoulder, kg	10.04^{b}	10.23^{ab}	10.17^{ab}	10.46^{a}	0.11	10.18^{b}	10.08^{b}	10.41^{a}	0.07	D, M
% HCW	20.05^{c}	20.18^{bc}	20.44^{ab}	20.57^{a}	0.12	20.55^{a}	20.21^{b}	20.17^{b}	0.10	S, M
Bone-in Boston, kg	4.10^{b}	4.18^{ab}	4.18^{ab}	4.31^{a}	0.06	4.26^{a}	4.01^{b}	4.29^{a}	0.04	M
% HCW	8.18^{b}	8.24^{ab}	8.41^{a}	8.47^{a}	0.08	8.61^{a}	8.05^{c}	8.33^{b}	0.06	S, M, SDM
Boneless Boston, kg	3.81^{b}	3.88^{ab}	3.89^{ab}	4.02^{a}	0.06	3.94^{a}	3.75^{b}	4.01^{a}	0.04	M
% HCW	7.61^{b}	7.66^{b}	7.83^{ab}	7.91^{a}	0.09	7.95^{a}	7.52^{b}	7.78^{a}	0.07	S, M, SDM
Bone-in picnic, kg	4.85^{c}	4.96^{bc}	5.06^{ab}	5.14^{a}	0.05	4.98	5.00	5.03	0.03	S
% HCW	9.70^{b}	9.80^{b}	10.18^{a}	10.12^{a}	0.08	10.06^{a}	10.03^{a}	9.76^{b}	0.06	S, M
Boneless picnic, kg	3.64^{b}	3.75^{ab}	3.79^{a}	3.87^{a}	0.04	3.73^{b}	3.74^{ab}	3.82^{a}	0.03	S, D
% HCW	7.27^{b}	7.40^{b}	7.63^{a}	7.61^{a}	0.06	7.53	7.50	7.40	0.06	S
Cushion, kg	2.01^{b}	2.01^{b}	2.06^{ab}	2.13^{a}	0.03	2.10^{a}	2.00^{b}	2.07^{a}	0.02	S, M
% HCW	4.02^{bc}	3.97^{c}	4.15^{ab}	4.19^{a}	0.06	4.24^{a}	4.00^{b}	4.01^{b}	0.05	S, M
Jowl, kg	1.20	1.19	1.13	1.14	0.04	1.10^{b}	1.13^{b}	1.27^{a}	0.03	M
% HCW	2.39	2.35	2.27	2.23	0.07	2.21^{b}	2.26^{b}	2.46^{a}	0.05	M

[a, b, c] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= fed diet treatment for 12 d prior to harvest (4.5 wk post-second Improvest dose); 2 = fed diet treatment for 19 d prior to harvest (5.5 wk post-second Improvest dose); 3 = fed diet treatment for 33 d prior to harvest (7.5 wk post-second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Table 4.3. Effects of physical castrate and immunological castrate finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of marketing group on left side carcass cut-out values from the loin.[1]

	Physical Castrate		Immunological Castrate			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Whole loin, kg	13.05^{ab}	13.42^{a}	12.79^{b}	13.18^{ab}	0.17	13.04^{ab}	12.98^{b}	13.31^{a}	0.12	D
% HCW	26.02^{ab}	26.50^{a}	25.73^{b}	25.89^{b}	0.21	26.30	25.99	25.81	0.18	S
Trimmed loin, kg	9.92^{b}	10.35^{a}	10.08^{ab}	10.48^{a}	0.15	10.25	10.11	10.26	0.11	D
% HCW	19.76^{b}	20.44^{a}	20.27^{a}	20.59^{a}	0.17	20.68^{a}	20.23^{a}	19.88^{b}	0.14	S, D, M
Canadian back, kg	3.55^{b}	3.76^{ab}	3.63^{a}	3.83^{a}	0.07	3.68	3.68	3.70	0.05	D, DM
% HCW	7.07^{b}	7.42^{a}	7.30^{ab}	7.52^{a}	0.10	7.44^{a}	7.38^{a}	7.16^{b}	0.08	S, D, M
Tenderloin, kg	0.47^{b}	0.51^{a}	0.48^{ab}	0.51^{a}	0.01	0.49	0.50	0.49	0.01	D, SM
% HCW	0.95^{b}	1.01^{a}	0.97^{ab}	1.00^{a}	0.02	0.99^{a}	1.01^{a}	0.95^{b}	0.01	D, M, SM
Sirloin, kg	0.72^{b}	0.77^{ab}	0.74^{b}	0.80^{a}	0.02	0.75	0.77	0.76	0.02	D, SM
% HCW	1.43^{b}	1.52^{ab}	1.49^{ab}	1.58^{a}	0.03	1.50	1.54	1.48	0.03	D, SM
Backribs, kg	0.82	0.84	0.82	0.84	0.01	0.83^{b}	0.78^{c}	0.88^{a}	0.01	M
% HCW	1.64	1.66	1.65	1.64	0.03	1.68^{a}	1.56^{b}	1.71^{a}	0.02	M

[a, b, c] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= fed diet treatment for 12 d prior to harvest (4.5 wk post-second Improvest dose); 2 = fed diet treatment for 19 d prior to harvest (5.5 wk post-second Improvest dose); 3 = fed diet treatment for 33 d prior to harvest (7.5 wk post-second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Table 4.4. Effects of physical castrate and immunological castrate finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of marketing group on left side carcass cut-out values from the ham.[1]

	Physical Castrate		Immunological Castrate			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Whole ham, kg	11.69	11.83	11.76	11.98	0.12	11.84	11.81	11.79	0.08	-
% HCW	23.35^{b}	23.37^{ab}	23.69^{a}	23.57^{ab}	0.13	23.92^{a}	23.69^{a}	22.87^{b}	0.12	S, M
Trimmed ham, kg	9.60^{b}	9.87^{ab}	9.90^{a}	10.14^{a}	0.12	9.92	9.87	9.86	0.08	S, SM, DM
% HCW	19.17^{b}	19.51^{b}	19.96^{a}	19.96^{a}	0.15	20.04^{a}	19.78^{a}	19.13^{b}	0.12	S, M, SM
Inside, kg	1.66^{b}	1.73^{ab}	1.73^{ab}	1.76^{a}	0.03	1.72	1.70	1.74	0.02	-
% HCW	3.32^{b}	3.42^{ab}	3.49^{a}	3.46^{a}	0.05	3.48^{a}	3.42^{ab}	3.37^{b}	0.04	S
Outside, kg	2.34^{b}	2.41^{ab}	2.44^{ab}	2.48^{a}	0.04	2.43	2.39	2.43	0.03	S
% HCW	4.68^{c}	4.76^{bc}	4.92^{a}	4.88^{ab}	0.05	4.91^{a}	4.80^{ab}	4.72^{b}	0.05	S, M
Knuckle, kg	1.32^{b}	1.38^{ab}	1.37^{ab}	1.42^{a}	0.02	1.37	1.36	1.39	0.02	S
% HCW	2.63^{b}	2.72^{ab}	2.76^{a}	2.79^{a}	0.03	2.76	2.72	2.70	0.03	S
Light butt, kg	0.44^{c}	0.45^{bc}	0.48^{ab}	0.49^{a}	0.01	0.48^{a}	0.48^{a}	0.44^{b}	0.01	S, M, DM
% HCW	0.87^{b}	0.90^{b}	0.97^{a}	0.96^{a}	0.02	0.97^{a}	0.95^{a}	0.85^{b}	0.02	S, M, DM

$^{a, b, c}$ Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= fed diet treatment for 12 d prior to harvest (4.5 wk post-second Improvest dose); 2 = fed diet treatment for 19 d prior to harvest (5.5 wk post-second Improvest dose); 3 = fed diet treatment for 33 d prior to harvest (7.5 wk post-second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Table 4.5. Effects of physical castrate and immunological castrate finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of marketing group on left side carcass cut-out values from the belly.[1]

	Physical Castrate		Immunological Castrate			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Whole belly, kg	10.09^{a}	10.00^{ab}	9.73^{b}	9.93^{ab}	0.13	9.68^{b}	10.15^{a}	9.98^{a}	0.10	S, M
% HCW	20.14^{a}	19.72^{ab}	19.54^{b}	19.53^{b}	0.23	19.54^{b}	20.36^{a}	19.29^{c}	0.20	S, M
Spareribs, kg	1.76^{b}	1.77^{b}	1.78^{b}	1.85^{a}	0.02	1.79^{ab}	1.81^{a}	1.77^{b}	0.02	S
% HCW	3.51^{ab}	3.50^{b}	3.58^{ab}	3.64^{a}	0.05	3.62^{a}	3.64^{a}	3.42^{b}	0.04	S, M
Natural fall belly, kg	8.33^{a}	8.23^{ab}	7.94^{b}	8.08^{ab}	0.12	7.88^{b}	8.34^{a}	8.21^{a}	0.10	S, M
% HCW	16.63^{a}	16.22^{ab}	15.96^{b}	15.89^{b}	0.21	15.92^{b}	16.73^{a}	15.88^{b}	0.18	S, M
Squared belly, kg	6.78^{a}	6.73^{ab}	6.50^{b}	6.63^{ab}	0.11	6.46^{c}	6.87^{a}	6.66^{b}	0.09	S, M
% HCW	13.54^{a}	13.27^{ab}	13.05^{b}	13.04^{b}	0.21	13.05^{b}	13.77^{a}	12.87^{b}	0.20	S, M

$^{a, b, c}$ Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= fed diet treatment for 12 d prior to harvest (4.5 wk post-second Improvest dose); 2 = fed diet treatment for 19 d prior to harvest (5.5 wk post-second Improvest dose); 3 = fed diet treatment for 33 d prior to harvest (7.5 wk post-second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Table 4.6. Effects of physical castrate and immunological castrate finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of marketing group on lean cutting yields and total carcass cutting yields.[1]

	Physical Castrate		Immunological Castrate			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Boneless lean yield[4]	35.83[c]	36.85[b]	37.35[ab]	37.72[a]	0.30	37.55[a]	36.83[b]	36.43[b]	0.24	S, M
Bone-in lean yield[5]	56.74[c]	57.94[b]	58.82[a]	59.14[a]	0.30	59.41[a]	58.02[b]	57.04[c]	0.25	S, D, M, SM
Carcass cutting yield[6]	70.29[c]	71.31[b]	71.93[ab]	72.31[a]	0.24	72.46[a]	71.79[b]	70.13[c]	0.20	S, D, M, SM

[a, b, c] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= fed diet treatment for 12 d prior to harvest (4.5 wk post-second Improvest dose); 2 = fed diet treatment for 19 d prior to harvest (5.5 wk post-second Improvest dose); 3 = fed diet treatment for 33 d prior to harvest (7.5 wk post-second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

[4] Boneless lean yield = [2 × (boneless Boston butt + boneless picnic + Canadian back + tenderloin + sirloin + light butt + knuckle + inside ham + outside ham) / HCW] × 100

[5] Bone-in lean yield = [2 × (trimmed Boston butt + trimmed picnic + trimmed loin + trimmed ham) / HCW] × 100

[6] Carcass cutting yield = [2 × (components from lean yield + squared belly) / HCW] × 100

Table 4.7. Effects of physical castrate and immunological castrate finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of marketing group on pork loin quality characteristics.[1]

	Physical Castrate		Immunological Castrate			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Ventral side										
Color[4]	3.48	3.53	3.38	3.38	0.08	2.88^{c}	3.88^{a}	3.57^{b}	0.07	M
Marbling[4]	1.65^{a}	1.46^{b}	1.36^{b}	1.28^{b}	0.07	1.55^{a}	1.41^{ab}	1.36^{b}	0.06	S
Firmness[4]	2.56^{ab}	2.61^{a}	2.34^{b}	2.44^{ab}	0.09	2.50	2.52	2.44	0.07	S
Cut surface										
Color[4]	2.87^{ab}	2.97^{a}	2.74^{b}	2.86^{ab}	0.07	2.88^{ab}	2.93^{a}	2.78^{b}	0.06	-
Marbling[4]	1.73^{a}	1.42^{b}	1.42^{b}	1.38^{b}	0.08	1.54	1.42	1.50	0.07	S, SM
Firmness[4]	2.67^{a}	2.72^{a}	2.46^{b}	2.60^{ab}	0.09	2.50^{b}	2.53^{b}	2.81^{a}	0.07	S, M
*L**[5]	46.47	45.84	46.35	45.75	0.37	46.07^{b}	44.66^{c}	47.58^{a}	0.29	M
*a**[5]	7.82	7.52	7.53	7.29	0.22	7.41^{b}	7.06^{c}	8.16^{a}	0.17	M
*b**[5]	1.90^{a}	1.50^{ab}	1.61^{ab}	1.31^{b}	0.16	1.02^{b}	1.11^{b}	2.61^{a}	0.11	D, M, SM
pH	5.59	5.60	5.57	5.59	0.01	5.67^{a}	5.56^{b}	5.53^{c}	0.01	M
Drip loss, %	1.82^{ab}	1.73^{b}	2.13^{a}	2.02^{ab}	0.14	1.99	1.96	1.82	0.12	S
14 d purge loss, %	1.70	1.71	2.02	1.86	0.14	2.39^{a}	1.86^{b}	1.21^{c}	0.12	M
LM composition										
Moisture, %	73.57^{c}	74.01^{b}	74.33^{a}	74.31^{a}	0.11	74.65^{a}	74.20^{b}	73.32^{c}	0.09	S, SD, M
Lipid, %	2.94^{a}	2.45^{b}	2.30^{b}	2.23^{b}	0.10	2.04^{c}	2.39^{b}	3.01^{a}	0.09	S, D, SD, M, SM
Cook loss, %[6]	22.31	21.66	22.47	22.34	0.60	22.43	21.49	22.68	0.52	-
Shear force, kg[6]	2.76^{ab}	2.73^{b}	2.88^{ab}	2.93^{a}	0.07	3.02^{a}	2.72^{b}	2.72^{b}	0.06	S, M

[a, b, c] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] Male pigs immunologically castrated by giving 2 doses of Improvest® (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1= 12 d on RAC (4.5 wk post-second injection); 2 = 19 d on RAC (5.5 wk post-second injection); 3 = 33 d on RAC (7.5 wk post-second injection).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

[4] Evaluated according to the National Pork Producers Council standards for color and marbling (NPPC, 1999) and firmness (NPPC, 1991).

[5] *L** = lightness; *a** = redness; *b** = yellowness

[6] Values represent means at 14 d post-mortem

Chapter 5

EFFECTS OF FEEDING RACTOPAMINE HYDROCHLORIDE (PAYLEAN®) TO PHYSICALLY AND IMMUNOLOGICALLY CASTRATED (IMPROVEST®) PIGS IN A COMMERCIAL SETTING ON HAM AND BELLY FURTHER PROCESSING CHARACTERISTICS

ABSTRACT

Two hundred eighty-five carcasses were used in this study to evaluate the effects of feeding ractopamine (RAC; 5 mg/kg) to physically castrated (PC) and immunologically castrated (IC) pigs on fresh ham and belly characteristics. Male pigs were randomly assigned to sex treatments at birth and fed the same nursery diets prior to allotment in a grow-finish barn. Pigs in the PC group were physically castrated at 5 d of age and pigs in the IC group were administered Improvest at 11 and 18 wk of age. Diet treatments (control or RAC) were initiated on d 87 of study and final treatment arrangement was a 2 x 2 factorial of sex and diet. Pigs were slaughtered in three groups based on ending live weight. One carcass from each pen per market group was selected to evaluate further processing characteristics. Data were analyzed using PROC MIXED in SAS with fixed effects of sex, diet, market group, and their interaction and carcass served as the experimental unit. Fresh bellies from PC carcasses were thicker ($P<0.01$) and firmer ($P<0.01$) than those from IC carcasses. This was due in part to bellies from IC carcasses having more ($P<0.01$) unsaturated fatty acids than PC carcasses. Cured hams and bellies from IC carcasses had less ($P<0.05$) fat than those from PC carcasses. Feeding RAC had increased ($P<0.05$) iodine values in both PC and IC carcasses while decreasing ($P<0.01$) cured belly fat content in PC carcasses. There were differences ($P < 0.05$) between market groups for multiple

characteristics measured including fresh ham and belly quality, ham and belly processing characteristics, and finished product composition. Overall, immunological castration and RAC produced leaner finished products without having any negative impacts on further processing yields.

Key words: Paylean; Improvest; further processing

INTRODUCTION

Further processed pork products constitute approximately 79% of all pork consumed; while ham and bacon make up approximately two-thirds of all processed pork products consumed (National Pork Board, 2009). Factors including genetics, nutrition, and management strategies during production can have an impact on fresh pork quality and ultimately have an effect on further processed products produced from these pigs. Inclusion of metabolic modifiers such as ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) in finishing swine diets improves pork carcass leanness and muscling (Armstrong et al., 2004, 2005; Apple et al., 2007b; Patience et al., 2009; Carr et al., 2009; Kutzler et al., 2011) while minimally impacting fresh meat quality (Rincker et al., 2005). Feeding RAC in finishing diets has also shown to improve processing yields of shoulder muscles (Tavárez et al., 2012), ham muscles (Boler et al., 2011b), and bellies (Scramlin et al., 2008).

Improvest® (Zoetis, Kalamazoo, MI) is an immunological product that was developed for the control of boar taint in intact male pigs. Carcasses from immunologically castrated (IC) pigs are leaner than those from physically castrated (PC) pigs (Jaros et al., 2005; Pauly et al., 2009). Other than producing leaner finished products and having increased fatty acid unsaturation, little differences have been reported regarding further processing yields of hams (Boler et al., 2011a) and bellies (Boler et al., 2012) between PC and IC carcasses.

While studies have shown that feeding RAC and immunological castration are additive in terms of improving carcass characteristics (Moore et al., 2009; Rikard-Bell et al., 2009), there is limited data documenting the effects of feeding RAC to PC and IC pigs simultaneously on further processing characteristics of hams and bellies. Therefore, the objective of this study was to evaluate the effects of feeding RAC to PC and IC pigs in a commercial setting on further processing characteristics of hams and bellies.

MATERIALS AND METHODS

No approval from the University of Illinois Institutional Animal Care and Use Committee was obtained for this study because only carcasses were obtained from a federally inspected slaughter facility before being transported to the University of Illinois. All animals used during the live phase of this study were cared for in accordance with University of Missouri Animal Care and Use Committee guidelines.

Animals and Housing

Pigs used in this study were a subset of those from Chapter 3 and carcasses used in this portion of the study were those used in Chapter 4.

Carcass Fabrication

Following chilling, skin-on hams and bellies (spareribs left on) were collected from left sides of carcasses destined for from the three pigs closest to the pen mean per marketing group. Primals were bulk packaged and transported to the University of Illinois Meat Science Lab for further data collection. Carcasses were fabricated according to guidelines of the Institutional Meat Purchasing Specifications (IMPS) as described by the North American Meat Processors Association (NAMP, 2007). Whole hams were skinned, excess fat removed, and fabricated to yield IMPS#402F inside and IMPS#402E outside hams. Whole sparerib-in bellies were

fabricated to yield IMPS#408 bellies and IMPS#416 spareribs. Teat lines were removed and flank ends squared to produce trimmed and squared bellies.

Fresh Ham Quality

Ham quality measurements including pH and instrumental color were obtained on the *m. semimembranosus* at an area adjacent to the location of the ball of the femur. Ultimate pH using a pH star probe equipped with a glass electrode (SFK Technologies Inc., Cedar Rapids, IA; calibrated at 2 points, pH 4 and 7). Objective CIE *L**, *a**, and *b** (CIE, 1978) measurements were collected with a Minolta CR-400 Chroma meter (Minolta Camera Company, Osaka, Japan) using a D65 illuminant, a 0° observer, an 8 mm aperture, and a Minolta DP-400 Data Processor calibrated to a white tile of known values. Paired inside and outside hams (N=96) from the carcass of the pig closest to the pen average for each marketing group were identified, packaged, and frozen (-33°C) until analysis for further processing characteristics.

Ham Manufacturing and Analysis

Frozen inside and outside hams were allowed to thaw (4°C) for 4 d prior to processing. Paired ham pieces were placed in poly bags and tied to keep paired pieces together. Ham pieces within bags were weighed to determine green weight and then pumped with a multi-needle brine injector through the bags (Schroder Injector/Marinator model N50, Wolf-Tec Inc., Kingston, NY) with a cure solution to a target of 130% of green weight, and reweighed to determine pump uptake. Cure solution was formulated to have final products contain 1.86% salt, 0.41% phosphate blend, 0.06% sodium erythorbate, 0.14% sugar, and 0.02% sodium nitrite. Pump uptake % was calculated using the following equation: Pump uptake % = [(pumped weight – green weight) / green weight] × 100. Ham pieces were removed from poly bags, macerated (model IT-3, Wolfking Belam, Uden, Holland) twice, placed in a new poly bag, and tumbled (model 89 EZ, Zuber Inc., Eden Prairie, MN) for 1.5 h with 70 kPa of vacuum. Following

tumbling, hams were oriented so that inside portions were positioned over outside portions, stuffed into ham nettings, and nettings tightened and clipped with a pneumatic clipper (Tipper Tie Inc., Apex, NC). Hams were weighed to determine stuffed weight, placed on racks, and cooked in a smokehouse (Alkar, Lodi, WI) to an ending internal temperature of 65.5°C. Hams were placed in a cooler for 24 h, allowed to cool to 4°C, and weighed to determine cooked weights and yield. Cooked yields were determined using the following equation: Cooked yield = (cooked weight / green weight) × 100.

Following weighing, a steak (2.4 cm) was cut from the approximate center of each ham for cured color, binding strength, and protein fat free determination. Cured color was determined by measuring CIE *L**, *a**, and *b** (CIE, 1978) at 4 locations (2 on the *biceps femoris* portion and 2 on the *semimembranosus* portion) on the steak surface with a Minolta CR-400 Chroma meter. Values were then averaged across all 4 locations to determine average cured color of hams. Following cured color evaluation, a 5-cm-wide section of each ham steak containing only the *biceps femoris* and *semimembranosus* was obtained perpendicular to the seam of the two muscles for binding strength evaluation. Sections were broken using a Texture Analyzer TA.HD Plus (Texture Texhnologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) equipped with 10 mm diameter bar with a blade speed of 3.3 mm/sec, a load cell capacity of 100 kg, and a 3.81 cm platform gap. Values were reported as kilograms of force required to break the seam. After binding strength evaluation, all components of the ham steak were homogenized in a food processor (Cuisinart model CUI DFP-7BC, Cuisinart, East Windsor, NJ), and duplicate 10 g samples were oven dried at 110° C for approximately 24 h to determine moisture content. Dried samples were then washed multiple times in an mixture of warm chloroform:methanol (4:1) as described by Novakofski et al. (1989) to determine total extractable lipid. Extracted samples

were then pulverized in a coffee grinder (Mr. Coffee Coffee Mill model IDS77, Sunbeam Products Inc., Bocaraton, FL) and duplicates of each sample combined to form one sample for protein analysis. Nitrogen content for protein analysis was determined by the combustion method (AOAC, 2000; 990.03) (model TruMac, LECO Corp., St. Joseph, MI) using EDTA as a standard.

Fresh Belly Characteristics

Twenty-four hours prior to evaluation, trimmed and squared bellies (N=285) were placed on tables, covered with polyvinyl film, and chilled (2˚C). Characteristics measured included length, width, thickness, and firmness. Length and width were measured with a ruler at the midpoint of the cross-sectional and longitudinal axis, respectively. Thickness was measured at 8 locations on the belly using a stainless steel probe. Measurements 1 through 4 were equally spaced and obtained on the dorsal half of the belly starting at the anterior end and working to the posterior end. Measurements 5 through 8 were obtained similarly to measurements 1 through 4 but on the ventral half of the belly. Belly firmness was determined by using the flop method where bellies were draped over a stationary bar skin side down perpendicular to the length of the belly. One measurement was taken between the two skin edges. The belly from the carcass of the pig closest to the pen average for each marketing group (N=96) was identified, vacuum packaged, and frozen (-33˚C) until analysis for processing characteristics.

Fatty Acid Analysis

A sample of subcutaneous fat tissue comprised of all three layers was obtained from the anterior dorsal corner of each fresh belly. Samples were frozen (-33˚C) and shipped for fatty acid analysis. Analysis was conducted following the procedures of Wiegand et al. (2011) and compositions reported as a percent of total fatty acids. Iodine values were calculated based on

fatty acid compositions using the following formula: iodine value = (0.95 × C16:1) + (0.86 × C18:1) + (1.732 × C18:2) + (2.616 × C18:3) + (0.785 × C20:1); AOCS (1998).

Bacon Manufacturing and Analysis

Skin-on frozen squared bellies were allowed to thaw (4°C) for 4 d prior to processing. After thawing, bellies were removed from vacuum packages, placed on wire racks, allowed to drip for 20 min, and weighed to determine green weights. Bellies were pumped with a multi-needle brine injector (Schroder Injector/Marinator, model N50, Wolf-Tec Inc., Kingston, NY) with a cure solution to a target of 110% of green weight, and reweighed to determine pump uptake. Cure solution was formulated to have the final product contain 1.86% salt, 0.41% phosphate blend, 0.06% sodium erythorbate, 0.14% sugar, and 0.02% sodium nitrite. Pump uptake % was calculated using the following equation: Pump uptake % = [(pumped weight – green weight) / green weight] × 100. Bellies were allowed to equilibrate for 72 h following injection and reweighed to determine equilibrated weight. Bellies were combed from blade ends and cooked in a smokehouse (Alkar, Lodi, WI) to an ending internal temperature of 60°C. Bellies were placed in a cooler for 24 h, allowed to cool to 4°C, and weighed to determine cooked weights. Cooked yields were determined using the following equation: Cooked yield = (cooked weight / green weight) × 100.

Following weighing, bellies were peeled and weighed to determine weights prior to slicing. Bellies were sliced (Trief model Puma 700F, Trief USA Inc., Shelton, CT) as a single draft to determine slicing yields. Bacon slices were classified into one of the following three grades: number 1 (slice length at least 20.3 cm, primary lean comprising at least 60% of the slice length, and secondary lean length at least 7.6 cm), number 2 (slice length greater than 12.7 cm and not meeting the specifications for a number 1 slice), or ends and pieces (slice length less than 12.7 cm). Slices that possessed quality issues including, but not limited to, hook marks and

cracks were downgraded a single grade. Slicing yield was calculated using the following equation: Slicing yield = (weight of slices / derind weight) × 100. Three slices were obtained at 25, 50, and 75% the length of the belly from the blade end for proximate composition analysis and image analysis. Bacon slice composition was determined by the drying and lipid extraction methods detailed above for cured ham composition. Compositions from all three locations were averaged to determine average composition for each cured belly and reported.

For image analysis, digital images of remaining slices were captured (Nikon D60, Nikon Instruments Inc., Melville, NY) and converted to black and white TIFF files using a photo software program (Adobe Photoshop Elements 3.0, Adobe Systems Inc., San Jose, CA). Each image included a ruler to calibrate measurements to known distances. Slice length and width along with secondary lean length were calculated using Adobe Photoshop Elements 3.0. Area of primary and secondary lean components was calculated by pixel density in ImageJ (Abramoff et al., 2004). Measurements from all three locations were averaged for each belly and reported.

Statistical Analysis

Data were analyzed using the MIXED procedure in SAS (SAS Inst., Cary, NC) and carcass served as the experimental unit for all analyses. Data were analyzed as a split-plot design with sex and diet combination serving as the whole plot and market group serving as the split plot. The model included the fixed effects of sex, diet, market group, and their interactions. Single degree of freedom contrast statements were used to make pair-wise comparisons between treatment groups for any significant interactions. Least squares means and coefficients for single degree of freedom contrast statements were generated using LSMEANS. Replication served as a random variable in all models. Normality of residuals was checked using the CAPABILITY procedure and outliers were left in the data set unless deemed physiologically impossible. Homogeneity of variances was tested using the Levene's test or the Brown and Forsythe's test in

the case of non-normal data using the GLM procedure in SAS. Effects were deemed significant at $P < 0.05$ and tendencies were reported if $0.05 \leq P < 0.10$.

RESULTS

Fresh Ham Quality

There were no significant interactions between sex, diet, and market group for any fresh ham quality characteristics (Table 5.1). There were no differences ($P \geq 0.41$) between PC and IC carcasses as well as no differences ($P \geq 0.15$) between control-fed and RAC-fed carcasses when evaluating pH and L* values; however, fresh hams from PC carcasses had greater ($P \leq 0.02$) a* and b* values than those from IC carcasses. While feeding RAC had no effects ($P \geq 0.15$) on fresh ham pH, L*, and b* values, hams from control-fed carcasses did have greater ($P = 0.03$) a* values than RAC-fed carcasses. Market group 1 carcasses had greater ($P = 0.01$) ham pH values than market group 2 carcasses which had greater ($P < 0.0001$) values than market group 3 carcasses; however, there were no differences ($P \geq 0.10$) between L* values of market group 1, 2, and 3 carcasses. Additionally, market group 3 carcasses had greater ($P < 0.0001$) fresh ham a* values than both market groups 1 and 2 carcasses while there were no differences ($P = 0.88$) between market group 1 and 2 carcasses. Market group 3 hams had greater ($P < 0.0001$) b* values than market group 2 hams which had greater ($P < 0.01$) values than market group 1 hams.

Ham Further Processing Characteristics

There was an interaction ($P = 0.04$) between sex, diet, and market group when evaluating ham pump uptakes expressed as a percentage of green weight (Table 5.1). Feeding RAC had no effect ($P \geq 0.21$) on pump uptakes of either sex in market groups 1 and 2; however, RAC increased ($P < 0.01$) pump uptakes of hams from PC carcasses by 5.5 percentage units in market group 3 while having no effect ($P = 0.21$) on pump uptakes of IC hams (Figure 5.1). There was also an interaction ($P = 0.01$) between sex and diet on ham cooked yields where RAC increased

($P < 0.01$) ham cooked yields in PC carcasses by 3.8 percentage units but had no effect ($P = 0.46$) in IC carcasses. There were no differences ($P \geq 0.43$) between PC and IC carcasses when evaluating ham green, pumped, stuffed, and cooked weights. Similarly, there were no differences ($P \geq 0.16$) between control-fed and RAC-fed carcasses when evaluating ham green, pumped, stuffed, and cooked weights. Additionally, market group 1 and 2 carcasses had greater ($P < 0.0001$) cooked ham yields than market group 3 carcasses while there were no differences ($P = 0.87$) between market group 1 and 2 carcasses. There were also no differences ($P \geq 0.17$) between carcasses from any market group when evaluating ham green, pumped, stuffed, and cooked weights.

Cured Ham Characteristics

There was an interaction ($P = 0.03$) between sex, diet, and market group for effects on cured ham L* values (Table 5.2). In market group 2, RAC increased ($P = 0.03$) L* values of cured hams from PC carcasses by 1.7 units while having no effect ($P = 0.94$) on hams from IC carcasses. Contrastingly, RAC decreased ($P = 0.04$) L* values of hams from PC carcasses by 1.7 units while having no effect ($P = 0.76$) on hams from IC carcasses in market group 3. Feeding RAC had no effects ($P \geq 0.57$) on cured ham L* values in market group 1 carcasses. There were no differences ($P \geq 0.57$) between PC and IC carcasses when evaluating cured ham a* and b* values. Additionally, there were no differences ($P \geq 0.42$) between control-fed and RAC-fed carcasses when evaluating cured ham a* and b* values. There were no differences ($P \geq 0.31$) between any market groups when evaluating cured ham a* values; however, market group 3 carcasses had greater ($P < 0.01$) cured ham b* values than both market group 1 and 2 carcasses while there were no differences ($P = 0.88$) between market group 1 and 2 carcasses.

There were interactions ($P \leq 0.04$) between sex, diet, and market group for effects on cured ham moisture and fat (Table 5.2). Feeding RAC increased ($P < 0.01$) cured ham moisture

of hams from PC carcasses by 2.0 percentage units in market group 1 while having no effect (P = 0.60) on those from IC carcasses (Figure 5.2). Feeding RAC had no effects ($P \geq 0.11$) on cured ham moisture in market groups 2 and 3. Similarly, feeding RAC decreased ($P < 0.01$) cured ham fat of hams from PC carcasses by 1.5 percentage units in market group 1 while having no effect (P = 0.35) on hams from IC carcasses (Figure 5.3). In market group 2, RAC decreased (P = 0.04) cured ham fat of hams from IC carcasses by 1.1 percentage units while having no effects (P = 0.70) on hams from PC carcasses. Feeding RAC had no effects ($P \geq 0.57$) on cured ham fat of hams from market group 3 carcasses. There were no differences ($P \geq 0.40$) between PC and IC carcasses as well as no differences ($P \geq 0.21$) between control-fed and RAC-fed carcasses when evaluating cured ham protein content and protein fat-free. There were no differences (P = 0.50) between PC and IC carcasses as well as no differences (P = 0.76) between of control-fed and RAC-fed carcasses when evaluating ham binding strengths.

Market group 3 carcasses had 1.6 percentage units more ($P < 0.0001$) cured ham protein content than both market group 1 and 2 carcasses while there were no differences (P = 0.39) between hams from market group 1 and 2 carcasses. Additionally, cured hams from market group 3 carcasses had 1.7 units greater ($P < 0.0001$) PFF values than hams from market group 1 and 2 carcasses while there were no differences (P = 0.69) between hams from market group 1 and 2 carcasses. There were no differences ($P \geq 0.12$) between ham binding strengths from any market group.

Fresh Belly Characteristics

There were no significant interactions between sex, diet, and market group for any fresh belly characteristics evaluated in this study (Table 5.3). There was an interaction ($P < 0.05$) between sex and diet when evaluating belly length; however, RAC had no effects ($P \geq 0.13$) on lengths of bellies from either sex group. There were no differences (P = 0.13) between PC and

IC carcasses when evaluating belly widths; however, bellies from PC carcasses were 0.29 cm thicker ($P < 0.0001$) than those from IC carcasses. Additionally, bellies from PC carcasses had 8.27 cm greater ($P < 0.0001$) flop distances than those from IC carcasses which is indicative of bellies from PC carcasses being firmer than those from IC carcasses. There were no differences ($P \geq 0.16$) between control-fed and RAC-fed carcasses when evaluating belly widths, thicknesses, and flop distances. Bellies from market group 2 carcasses were 0.80 cm longer ($P = 0.04$) than those from market group 3 carcasses which were 0.76 cm longer ($P < 0.05$) than those from market group 1 bellies. Additionally, bellies from market group 1 carcasses were 0.78 cm wider ($P < 0.01$) bellies than those from market group 2 carcasses which were 1.43 cm wider ($P < 0.0001$) than those from market group 3 carcasses. Market group 1 and 3 carcasses had on average 0.35 cm thicker ($P < 0.0001$) bellies than market group 2 carcasses while market group 1 and 3 carcasses had similar ($P = 0.43$) belly thicknesses. Bellies from market group 3 carcasses had 6.17 cm greater ($P < 0.0001$) flop distances than those from market group 2 carcasses which had 5.27 cm greater ($P < 0.0001$) flop distances than bellies from market group 1 carcasses.

Cured Belly Characteristics

There were no significant interactions between sex, diet, and market group when evaluating cured belly characteristics in this study (Table 5.3). There were interactions ($P \leq 0.03$) between sex and diet when evaluating belly green weights, pumped weights, pump uptakes, equilibrated weights, and cooked weights. Feeding RAC decreased ($P = 0.04$) green weights of bellies from PC carcasses by 0.39 kg but had no effect ($P = 0.18$) on bellies from IC carcasses. Similarly, RAC tended ($P = 0.09$) to decrease pumped weights of bellies from PC carcasses by 0.34 kg while having no effect ($P = 0.17$) on bellies from IC carcasses. Contrastingly, feeding RAC increased ($P < 0.01$) pump uptakes of bellies from PC carcasses by 1.14 percentage units while having no effect ($P = 0.70$) on bellies from IC carcasses. Feeding

RAC tended ($P = 0.09$) to decrease equilibrated belly weights in PC carcasses by 0.34 kg while having no effect ($P = 0.21$) on bellies from IC carcasses. There were no differences ($P = 0.62$) between PC and IC carcasses when evaluating belly cooked yields. Additionally, there were no differences ($P \geq 0.12$) between PC and IC carcasses when evaluating bacon slicing yields. There were no differences ($P = 0.54$) between control-fed and RAC-fed carcasses when evaluating belly cooked yields. Additionally, feeding RAC had no effect ($P \geq 0.21$) on bacon slicing yields.

Market group 2 carcasses had heavier ($P < 0.01$) green, pumped, and equilibrated bellies than market group 1 carcasses with market group 3 bellies being similar ($P \geq 0.09$) to other market groups when evaluating green, pumped, and equilibrated belly weights. Bellies from market group 1 carcasses had 0.75 percentage units greater ($P = 0.01$) pump uptakes than bellies from market group 3 carcasses while there were no differences ($P \geq 0.17$) market group 2 carcasses and any other market group. Cooked bellies from market group 2 and 3 carcasses were on average 0.33 kg heavier ($P \leq 0.03$) than those from market group 1 carcasses while there were no differences ($P = 0.37$) between bellies from market group 2 and 3 carcasses. Bellies from market group 3 carcasses had on average 1.02 percentage units greatest ($P < 0.001$) cooked yields than bellies from market group 1 and 2 carcasses while bellies from market group 1 and 2 carcasses had similar ($P = 0.49$) cooked yields. Market group had no effects ($P \geq 0.82$) on any bacon slicing yields evaluated.

Bacon Slice Characteristics and Composition

There were no significant interactions between sex, diet, and market group when evaluating any bacon slice characteristics in this study (Table 5.4). There were interactions ($P \leq 0.03$) between sex and diet when evaluating bacon slice width and bacon slice area. Feeding RAC decreased ($P = 0.03$) bacon slice widths in PC carcasses by 0.26 cm but had no effect ($P = 0.41$) on bellies from IC carcasses. Feeding RAC tended ($P = 0.06$) to decrease bacon slice areas

in PC carcasses by 6.15 sq. cm while having no effect ($P = 0.27$) on bacon slices from IC carcasses. There tended to be an interaction ($P = 0.05$) between sex and diet when evaluating bacon slice moisture content where RAC increased ($P = 0.01$) moisture content of bacon slices from PC carcasses by 3.27 percentage units while having no effect ($P \geq 0.20$) on bacon slices from IC carcasses. There was an interaction ($P = 0.03$) between sex and diet when evaluating bacon slice fat content where RAC decreased ($P < 0.01$) fat content of bacon slices from PC carcasses by 4.69 percentage units while having no effect ($P = 0.98$) on bacon slices from IC carcasses. There were no differences ($P \geq 0.18$) between PC and IC carcasses when evaluating bacon slice length, lean area, secondary lean length, secondary lean area, and slice lean area expressed as a percentage of total slice area. Feeding RAC tended ($P = 0.07$) to increase bacon slice lean areas when expressed as a percentage of total slice area by 2.35 percentage units. Feeding RAC had no effects ($P \geq 0.23$) on bacon slice length, lean area, secondary lean length, and secondary lean area. Bacon slices from market group 2 and 3 carcasses were on average 0.20 cm wider ($P \leq 0.02$) than bacon slices from market group 1 carcasses while there were no differences ($P = 0.76$) between market group 2 and 3 carcasses. Additionally, bacon slices from market group 3 carcasses were on average 6.10 sq. cm larger ($P \leq 0.02$) than bacon slices from both market group 1 and 2 carcasses while there were no differences ($P = 0.75$) between market group 1 and 2 carcasses. Furthermore, market group had no effects ($P \geq 0.27$) on bacon slice length, lean area, secondary lean length, secondary lean area, and slice lean area when expressed as a percentage of total slice area.

Fatty Acid Composition

There was an interaction ($P < 0.001$) between sex, diet, and market group for effects on total SFA (Table 5.5). In market group 1, RAC tended ($P \leq 0.08$) to reduce total SFA for both sexes on average by 0.79 percentage units. In market group 2, RAC reduced ($P < 0.0001$) total

SFA in PC carcasses by 1.77 percentage units while increasing ($P = 0.03$) total SFA in IC carcasses by 0.93 percentage units (Figure 5.4). In market group 3, RAC reduced ($P < 0.0001$) total SFA in IC carcasses by 1.12 percentage units while having no effect ($P = 0.22$) in PC carcasses. Additionally, there tended ($P = 0.06$) to be an interaction between sex and diet for effects on total PUFA where RAC tended ($P = 0.07$) to increase total PUFA in PC carcasses by 0.41 percentage units but had no effect ($P = 0.41$) in IC carcasses. There was an interaction ($P = 0.03$) between sex and diet when evaluating PUFA:SFA where RAC increased ($P < 0.01$) ratios in PC carcasses by 0.03 units but had no effect ($P = 0.98$) in IC carcasses. There was an interaction ($P < 0.05$) between sex and diet for effects on total n-3 (omega-3) FA where RAC increased ($P = 0.01$) total n-3 FA in PC carcasses by 0.03 percentage units but had no effect ($P = 0.70$) in IC carcasses. There tended ($P = 0.07$) to be an interaction between sex and diet for effects on total n-6 (omega-6) FA concentrations; however, there were no differences ($P \geq 0.10$) between control-fed and RAC-fed carcasses when evaluated within each sex. There was an interaction ($P = 0.03$) between sex and diet for effects on C16:1 where RAC increased ($P = 0.03$) concentrations in IC carcasses by 0.20 percentage units but had no effect ($P = 0.39$) in PC carcasses.

There was an interaction ($P = 0.04$) between sex and market group for effects on total PUFA where IC carcasses had on average 1.12 percentage units greater ($P < 0.0001$) total PUFA than PC carcasses in market groups 1 and 2, but were similar ($P = 0.32$) in market group 3. Additionally, there was an interaction ($P = 0.02$) between sex and market group where IC carcasses had on average 0.04 units greater ($P < 0.01$) PUFA:SFA than PC carcasses in market groups 1 and 2, but ratios were similar ($P = 0.94$) in market group 3. There was an interaction ($P = 0.02$) between sex and market group for effects on total n-3 FA where IC carcasses had on

average 0.07 percentage units greater ($P < 0.05$) total n-3 FA concentrations than IC carcasses in all market groups. There also tended ($P = 0.06$) to be an interaction between sex and market group for effects on total n-6 FA where PC carcasses had greater ($P < 0.001$) concentrations than IC carcasses in market groups 1 and 2 but were similar ($P = 0.29$) in market group 3. There was an interaction ($P = 0.03$) between sex and market group for effects on C18:3; however, IC carcasses had on average 1.25 percentage units less ($P \leq 0.03$) C18:1 than PC carcasses across all marketing groups.

There was an interaction ($P = 0.02$) between diet and market group for effects on total MUFA where RAC increased ($P \leq 0.02$) concentrations in market group 2 and 3 carcasses by 1.28 and 1.78 percentage units, respectively; however, feeding RAC had no effect ($P = 0.56$) on total MUFA in market group 1 carcasses. There was an interaction ($P = 0.03$) between diet and market group for effects on C18:1 where RAC increased ($P \leq 0.02$) concentrations in market group 2 and 3 carcasses on average by 1.48 percentage units while having no effect ($P = 0.66$) in market group 1 carcasses.

Carcasses from PC pigs had 1.28 percentage units more ($P < 0.01$) total MUFA than those from IC pigs. Carcasses from IC pigs had 0.73 units greater ($P < 0.01$) n-6:n-3 than PC carcasses. Additionally, PC carcasses had more ($P < 0.0001$) C18:1 and C18:2 than IC carcasses. Carcasses from PC pigs tended ($P = 0.09$) to have more C20:1 than those from IC pigs. There were no differences ($P = 0.46$) between iodine values of PC and IC carcasses; however, feeding RAC increased ($P = 0.02$) iodine values by 0.98 units.

Market group 2 and 3 carcasses had greater ($P < 0.0001$) n-6:n-3 than market group 1 carcasses; however, there were no differences ($P = 0.73$) between market group 2 and 3 carcasses. Additionally, market group 2 carcasses had more ($P < 0.001$) C16:1 than market

group 1 carcasses while market group 3 carcasses were similar ($P \geq 0.05$) to those in the other market groups. There were no differences ($P = 0.27$) between control-fed and RAC-fed carcasses as well as no differences ($P \geq 0.51$) between market groups when evaluating C20:1. there were no differences ($P = 0.46$) between PC and IC carcasses as well as no differences ($P \geq 0.06$) between market groups when evaluating iodine values.

DISCUSSION

The interactions between sex and feeding RAC in the present study on further processing characteristics of hams and bellies were numerous; however, it is important to note that the use of immunological castration and RAC together had no greater impact on any characteristic evaluated than either technology used alone. The findings in the present study support the idea that these technologies can be used together without negatively impacting ham and belly processing yields. Feeding RAC in the present study had the greatest impact on products from PC carcasses while only minimally impacting products from IC carcasses. These RAC-induced effects on product leanness are attributed to the increased protein synthesis associated with feeding RAC (Adeola et al., 1992; Mersmann, 1998) where RAC limits the amount energy used for de novo fatty acid synthesis and ultimately decreases the saturation of fatty acids. When evaluating the use of RAC in IC pigs, it is important to note that the rate of protein accretion in IC pigs is much greater than seen in PC pigs (Dunshea et al., 2001) and RAC feeding may not impact fatty acid synthesis in IC pigs.

The findings in the present study agree with those of others who reported that feeding RAC has little impact on fresh ham quality (Fernández-Dueñas et al., 2008) while increasing cooked ham yields (Stites et al., 1991; Boler et al., 2011b). Similarly, feeding RAC in the present study resulted in leaner finished products which agrees with others who reported similar

results when evaluating cottage bacon (Tavárez et al., 2012), bacon (Scramlin et al., 2008), and cured hams (Boler et al., 2011c). Although RAC had little impact on fresh belly characteristics, feeding RAC did increase fatty acid unsaturation and overall iodine values of belly fat samples which agrees with the findings of others (Carr et al., 2005; Xi et al., 2005; Apple 2007a; Tavárez et al., 2012; Bohrer et al., 2013). These changes in composition, especially fatty acid composition, are expected given that RAC feeding has been shown to decrease de novo lipogenesis in porcine adipocytes (Mills et al., 1990) and ultimately decrease saturated fatty acid composition. Despite the changes seen in fatty acid saturation, feeding RAC in the present study proved to be an effective method to increase carcass leanness without negatively impacting fresh meat characteristics and further processing yields of hams and bellies.

Immunological castration in the present study had little impact on fresh ham quality and processing characteristics while producing leaner finished products which agrees with the findings of others (Boler et al., 2011a). Although bellies from IC carcasses were thinner and softer than those from PC carcasses, thickness and firmness greatly increased as time after second Improvest dose increased which agrees with Boler et al. (2012). Others have reported little differences in fatty acid composition (Boler et al., 2011a); however, IC carcasses in the present study had increased unsaturation. Despite these differences in saturation, there were no differences in iodine values between PC and IC carcasses. Immunological castration in the present study had minimal impacts on belly thickness and firmness; however, these differences did not impact on processing yields including cooked product and slicing yields.

In conclusion, feeding RAC to PC and IC pigs prior to slaughter improves final product leanness without negatively impacting further processing yields. Immunological castration and feeding RAC in the present study modified fatty acid composition; however, these differences

did not equate to reduced final product yields or slicing yields. Overall, further processed products produced from IC pigs fed RAC should be viewed as acceptable to processors and consumers.

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FIGURES

Figure 5.1. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and marketed in three groups on ham pump uptakes expressed as a percentage of green weight. Pigs in the IC group were immunologically castrated by administering Improvest at 11 and 18 wk of age. Pigs marketed in three groups based on ending live weight where market group 1 = 12 d on RAC (4.5 wk after second Improvest dose); market group 2 = 19 d on RAC (5.5 wk after second Improvest dose); market group 3 = 33 d on RAC (7.5 wk after second Improvest dose).

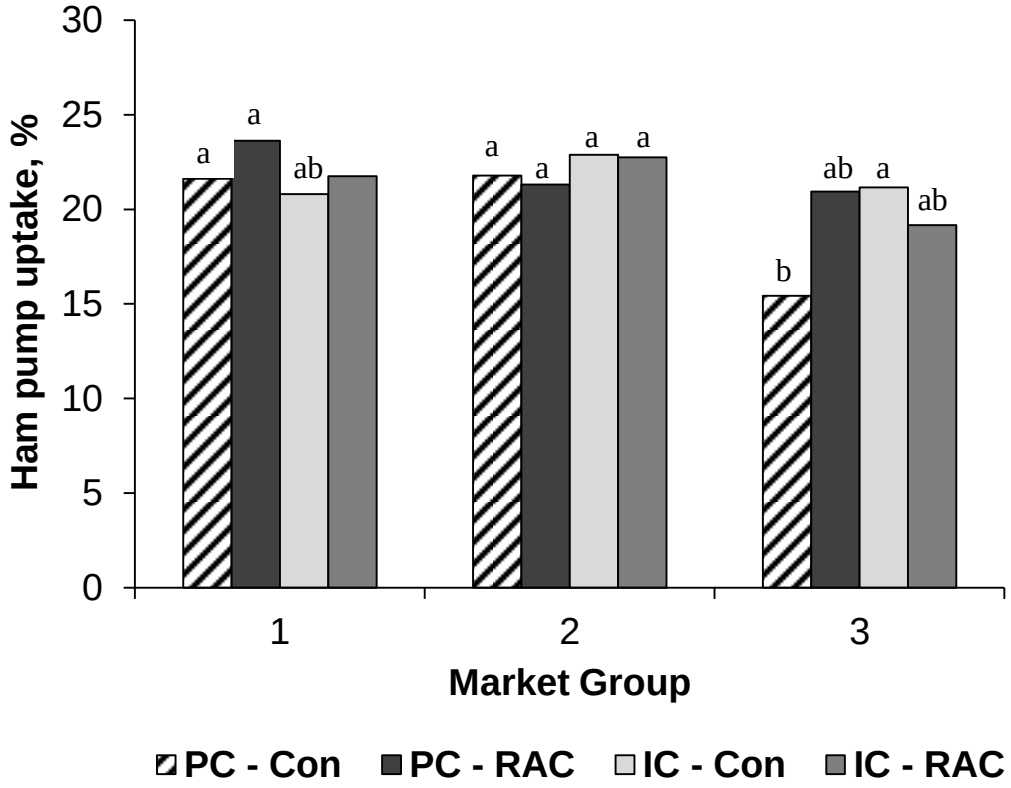


Figure 5.2. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and marketed in three groups on cured ham moisture content. Pigs in the IC group were immunologically castrated by administering Improvest at 11 and 18 wk of age. Pigs marketed in three groups based on ending live weight where market group 1 = 12 d on RAC (4.5 wk after second Improvest dose); market group 2 = 19 d on RAC (5.5 wk after second Improvest dose); market group 3 = 33 d on RAC (7.5 wk after second Improvest dose).

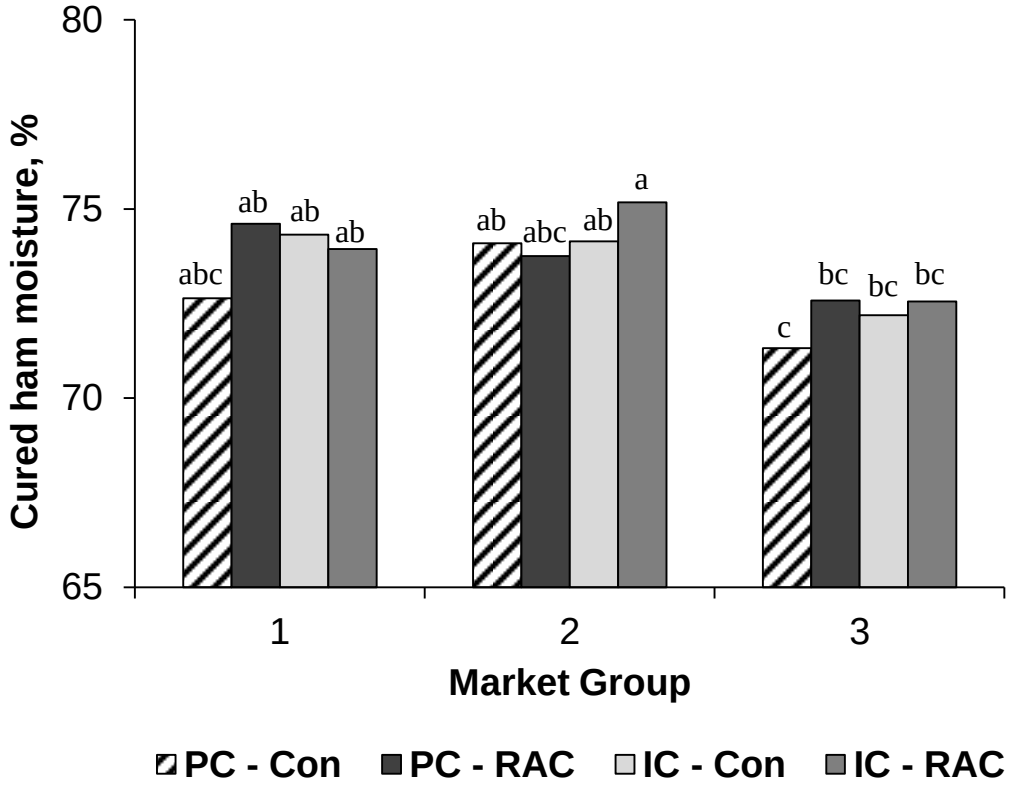


Figure 5.3. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and marketed in three groups on cured ham fat content. Pigs in the IC group were immunologically castrated by administering Improvest at 11 and 18 wk of age. Pigs marketed in three groups based on ending live weight where market group 1 = 12 d on RAC (4.5 wk after second Improvest dose); market group 2 = 19 d on RAC (5.5 wk after second Improvest dose); market group 3 = 33 d on RAC (7.5 wk after second Improvest dose).

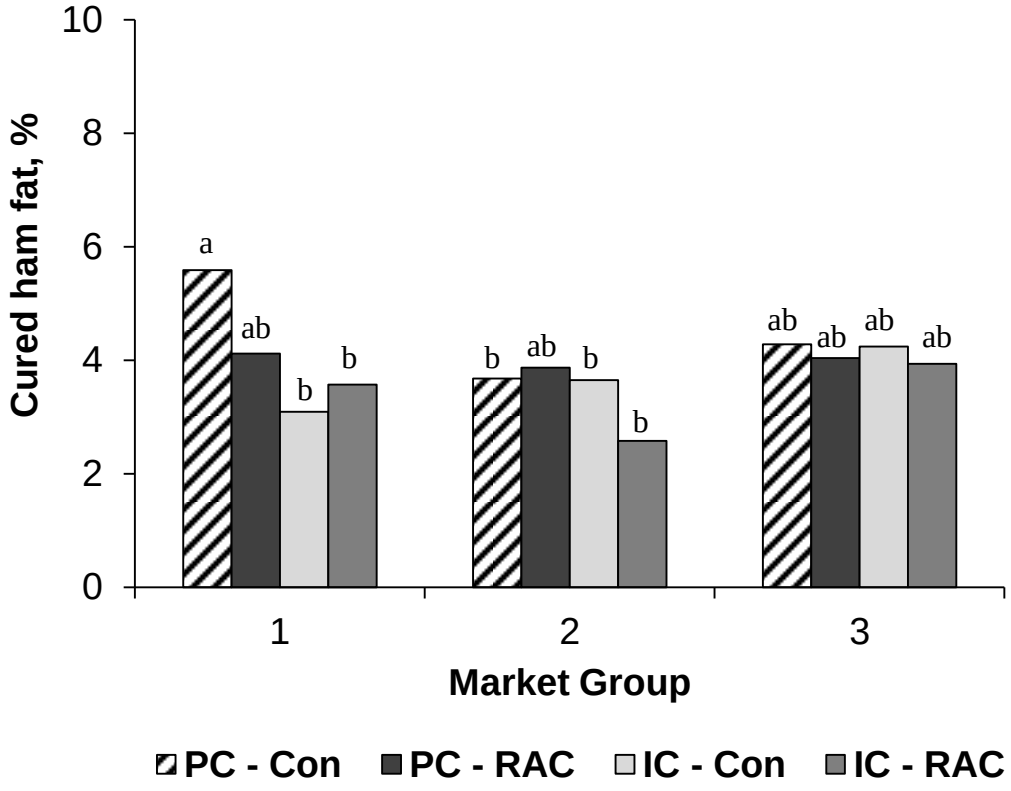
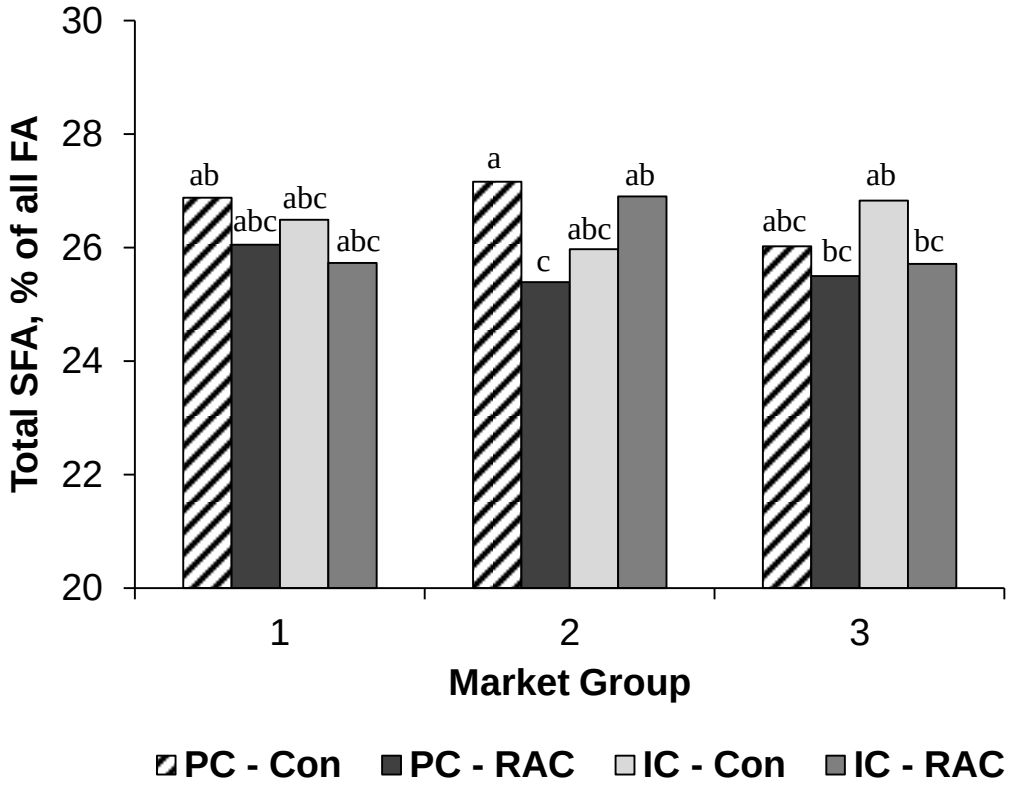


Figure 5.4. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and marketed in three groups on total saturated fatty acids (SFA) represented as a percent of total fatty acids. Pigs in the IC group were immunologically castrated by administering Improvest at 11 and 18 wk of age. Pigs marketed in three groups based on ending live weight where market group 1 = 12 d on RAC (4.5 wk after second Improvest dose); market group 2 = 19 d on RAC (5.5 wk after second Improvest dose); market group 3 = 33 d on RAC (7.5 wk after second Improvest dose).



TABLES

Table 5.1. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of market group on fresh ham quality and further processing characteristics.[1]

	PC		IC			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Fresh ham[4]										
pH	5.63	5.65	5.64	5.67	0.01	5.74^{a}	5.70^{b}	5.50^{c}	0.01	M
*L**	45.71	45.30	45.48	45.49	0.48	44.97	45.87	45.64	0.41	-
*a**	10.15^{a}	9.57^{ab}	9.55^{ab}	8.86^{b}	0.25	8.93^{b}	8.89^{b}	10.77^{a}	0.20	S, D, M
*b**	3.62^{a}	3.28^{ab}	3.01^{b}	2.83^{b}	0.23	2.21^{c}	2.86^{b}	4.48^{a}	0.19	S, M
Cured ham										
Green wt, kg	3.74	3.95	3.88	3.88	0.09	3.85	3.85	3.88	0.07	-
Pumped wt, kg	4.48	4.81	4.72	4.70	0.12	4.69	4.71	4.63	0.09	-
Pump uptake, %	19.62^{b}	21.96^{a}	21.61^{a}	21.22^{ab}	0.69	21.95^{a}	22.18^{a}	19.17^{b}	0.58	M, SDM
Stuffed wt, kg	4.24	4.59	4.52	4.48	0.10	4.47	4.48	4.43	0.08	-
Cooked wt, kg	3.74	4.09	3.99	3.95	0.10	3.99	3.99	3.85	0.08	-
Cooked yield, %	99.82^{b}	103.63^{a}	102.63^{a}	101.76^{ab}	0.86	103.52^{a}	103.35^{a}	99.01^{b}	0.74	SD, M

$^{a, b, c}$ Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1] [1]Male pigs immunologically castrated by administering Improvest (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1 = 12 d on RAC (4.5 wk after second Improvest dose); 2 = 19 d on RAC (5.5 wk after second Improvest dose); 3 = 33 d on RAC (7.5 wk after second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

[4] Measurements taken on *semimembranosus*; *L** = lightness; *a** = redness; *b** = yellowness.

Table 5.2. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of market group on cured ham characteristics.[1]

	PC		IC			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Cured color[4]										
*L**	64.93	64.80	65.12	65.05	0.37	65.26	64.98	64.68	0.34	SDM
*a**	12.17	11.94	11.95	12.19	0.21	11.97	12.04	12.17	0.16	-
*b**	6.25	5.99	6.00	6.08	0.12	5.93^{b}	5.94^{b}	6.36^{a}	0.10	M
Composition										
Moisture, %	72.68^{b}	73.65^{a}	73.55^{ab}	73.89^{a}	0.31	73.88^{a}	74.29^{a}	72.62^{b}	0.27	D, M, SDM
Fat, %	4.52^{a}	4.01^{ab}	3.66^{bc}	3.36^{c}	0.24	4.09^{a}	3.44^{b}	4.13^{a}	0.19	S, M, SM, SDM
Protein, %	19.48	19.03	19.50	19.50	0.26	18.72^{b}	18.97^{b}	20.44^{a}	0.22	M
PFF[5]	20.40	19.84	20.25	20.18	0.28	19.52^{b}	19.65^{b}	21.33^{a}	0.23	M
Binding strength, kg	3.92	3.76	3.93	3.98	0.17	3.99	4.02	3.68	0.14	-

[a, b, c] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1]Male pigs immunologically castrated by administering Improvest (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1 = 12 d on RAC (4.5 wk after second Improvest dose); 2 = 19 d on RAC (5.5 wk after second Improvest dose); 3 = 33 d on RAC (7.5 wk after second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

[4] Average measurements taken from *semimembranosus* and *biceps femoris*; *L** = lightness; *a** = redness; *b** = yellowness.

[5] Protein fat-free = [% protein / (100 - % fat)] × 100.

Table 5.3. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of market group on fresh and cured belly characteristics.[1]

	PC		IC			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Fresh belly										
Length, cm	64.96	64.27	64.27	64.83	0.33	63.80^{c}	65.37^{a}	64.57^{b}	0.28	SD, M
Width, cm	26.95	27.15	27.14	27.58	0.24	28.20^{a}	27.42^{b}	25.99^{c}	0.20	M
Thickness, cm	4.13^{a}	4.04^{a}	3.80^{b}	3.79^{b}	0.04	4.04^{a}	3.78^{b}	4.00^{a}	0.03	S, M
Flop distance, cm	36.33^{a}	33.99^{b}	26.49^{c}	26.68^{c}	0.94	25.15^{c}	30.42^{b}	36.59^{a}	0.78	S, M
Cured belly										
Green wt, kg	6.80^{a}	6.41^{b}	6.31^{b}	6.55^{ab}	0.13	6.30^{b}	6.71^{a}	6.52^{ab}	0.11	SD, M
Pumped wt, kg	7.23^{a}	6.89^{ab}	6.81^{b}	7.08^{ab}	0.14	6.80^{b}	7.22^{a}	6.98^{ab}	0.11	SD, M
Pump uptake, %	6.38^{b}	7.52^{a}	8.04^{a}	8.16^{a}	0.23	7.89^{a}	7.55^{ab}	7.14^{b}	0.21	S, D, SD, M
Equilibrated wt, kg	7.14^{a}	6.80^{ab}	6.70^{b}	6.95^{ab}	0.14	6.69^{b}	7.09^{a}	6.91^{ab}	0.11	SD, M
Cooked wt, kg	6.21^{a}	5.85^{b}	5.74^{b}	5.98^{ab}	0.12	5.73^{b}	6.11^{a}	6.00^{a}	0.10	SD, M
Cooked yield, %	91.32	91.22	91.01	91.34	0.22	90.80^{b}	90.96^{b}	91.90^{a}	0.20	M
Slicing yields, %										
No. 1 yield	90.98	90.34	90.43	89.50	0.67	90.53	90.29	90.11	0.58	-
No. 2 yield	5.66	6.30	6.48	7.42	0.62	6.27	6.48	6.65	0.54	-
Ends and pieces	2.78	2.95	2.85	3.10	0.18	2.92	2.99	2.85	0.16	-

[a, b, c] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1]Male pigs immunologically castrated by administering Improvest (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1 = 12 d on RAC (4.5 wk after second Improvest dose); 2 = 19 d on RAC (5.5 wk after second Improvest dose); 3 = 33 d on RAC (7.5 wk after second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Table 5.4. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of market group on average bacon slice characteristics.[1]

	PC		IC			Market group[2]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[3]
Slice length, cm	22.69	22.42	22.31	22.71	0.26	22.42	22.53	22.65	0.22	-
Slice width, cm	4.06[a]	3.80[b]	3.74[b]	3.83[b]	0.08	3.72[b]	3.93[a]	3.91[a]	0.06	SD, M
Slice area, cm^2	92.89	86.75	86.67	90.06	2.54	87.46[b]	86.67[b]	93.16[a]	2.15	SD, M
Lean area, cm^2	38.80	39.60	38.46	40.64	1.46	39.09	38.30	40.73	1.32	-
Sec. lean length, cm	19.94	20.26	19.77	20.04	0.29	20.20	19.87	19.94	0.24	-
Sec. lean area, cm^2	9.89	10.48	10.34	10.37	0.64	10.79	10.18	9.83	0.54	-
Slice lean area, %	41.57	45.33	44.13	45.07	1.02	44.44	44.08	43.56	0.87	-
Composition										
Moisture, %	44.25[b]	47.52[a]	48.93[a]	49.02[a]	0.86	48.01	47.35	46.94	0.73	S
Fat, %	41.77[a]	37.07[b]	35.21[b]	35.17[b]	1.16	36.53	37.59	37.79	0.98	S, SD

[a, b] Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1]Male pigs immunologically castrated by administering Improvest (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Market group: 1 = 12 d on RAC (4.5 wk after second Improvest dose); 2 = 19 d on RAC (5.5 wk after second Improvest dose); 3 = 33 d on RAC (7.5 wk after second Improvest dose).

[3] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

Table 5.5. Effects of physically castrated (PC) and immunologically castrated (IC) finishing pigs fed either a control diet or a diet containing 5 mg/kg ractopamine-HCl (RAC; Elanco Animal Health, Greenfield, IN) and main effects of market group on fatty acid (FA) composition of subcutaneous fat.[1,2]

	PC		IC			Market group[3]				Significant
Item	Control	RAC	Control	RAC	SEM	1	2	3	SEM	effects[4]
Total SFA	26.69^{a}	25.65^{c}	26.43^{ab}	26.11^{bc}	0.17	26.28	26.36	26.02	0.15	D, SD, SDM
Total MUFA	47.15^{ab}	48.02^{a}	45.82^{c}	46.79^{b}	0.39	46.60	47.34	46.90	0.35	S, D, DM
Total PUFA	11.21^{b}	11.62^{b}	12.35^{a}	12.16^{a}	0.16	11.79	11.72	11.99	0.14	S, SM
PUFA:SFA	0.42^{b}	0.45^{a}	0.47^{a}	0.47^{a}	0.01	0.45	0.44	0.46	0.01	S, D, SD, SM
Total n-3 FA	0.53^{c}	0.57^{b}	0.62^{a}	0.61^{a}	0.01	0.60^{a}	0.57^{b}	0.58^{ab}	0.01	S, SD, M, SM
Total n-6 FA	10.15^{b}	10.49^{b}	11.18^{a}	10.99^{a}	0.15	10.64	10.62	10.85	0.13	S
n-6:n-3	19.09^{a}	18.49^{ab}	18.13^{b}	17.99^{b}	0.21	17.81^{b}	18.76^{a}	18.70^{a}	0.16	S, M
C16:1	2.36^{a}	2.28^{ab}	2.17^{b}	2.37^{a}	0.07	2.14^{b}	2.45^{a}	2.30^{ab}	0.06	SD, M
C18:1	45.95^{ab}	46.76^{a}	44.60^{c}	45.61^{b}	0.38	45.34^{b}	46.15^{a}	45.71^{ab}	0.35	S, D, DM
C18:2	9.92^{b}	10.24^{b}	10.92^{a}	10.73^{a}	0.14	10.38	10.38	10.60	0.12	S
C18:3	0.47c	0.50b	0.54a	0.53a	0.01	0.51	0.51	0.51	0.01	S, SM
C20:1	0.87	0.89	0.85	0.86	0.01	0.87	0.86	0.87	0.01	-
Iodine value[5]	60.86^{b}	62.11^{a}	61.43^{ab}	62.14^{a}	0.41	61.05	62.00	61.85	0.36	D

$^{a, b, c}$ Means within row under main effect lacking common superscripts differ ($P < 0.05$).

[1]Male pigs immunologically castrated by administering Improvest (Zoetis, Kalamazoo, MI) at 11 wk and 18 wk of age.

[2] Fat samples obtained from the anterior dorsal edge of fresh bellies

[3] Market group: 1 = 12 d on RAC (4.5 wk after second Improvest dose); 2 = 19 d on RAC (5.5 wk after second Improvest dose); 3 = 33 d on RAC (7.5 wk after second Improvest dose).

[4] Significant effects ($P < 0.05$): S = sex; D = diet; M = market group; SD = sex × diet; SM = sex × market group; DM = diet × market group; SDM = sex × diet × market group.

[5] Iodine value = (0.95 × C16:1) + (0.86 × C18:1) + (1.732 × C18:2) + (2.616 × C18:3) + (0.785 × C20:1); AOCS (1998).